

Transit Oriented Development Strategy: Guangzhou Case Study

by

Satish McKay Lion

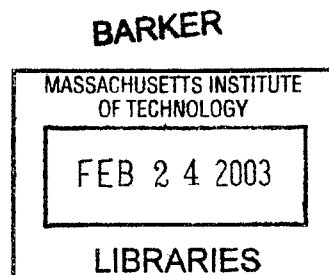
Bachelor of Science in Civil and Environmental Engineering
University of California Los Angeles (2001)

Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Civil and Environmental Engineering

at the

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Abstract

Mega-cities are the centers of population, economy, culture and political power. Yet, along with these characteristics, they are also the greatest source of energy consumption, resource depletion, and pollution. In order for developing countries to take a more sustainable development path, they must address their growing demand for energy and strive to find solutions to reduce their demand and increase their efficiency. Mega-cities stand out as natural targets for such solutions given their extreme population and waste generation.

Specifically, urban sprawl is a major source of energy inefficiency. Not only does it lead to more vehicle miles travels, more fuel consumption, more air pollution, but also to inefficiencies in infrastructure provision. De-densification of residential and commercial districts causes an increase in both energy services and materials.

Transit Oriented Development (TOD) is an effective method of fighting the negative impacts of urban sprawl, by reshaping the travel and land-use patterns into a more sustainable form. To achieve the full potential of a TOD it is critical to have long-term strategic planning, and cross-jurisdictional, complementary, and comprehensive policies and institutions. To effectively reduce energy consumption through TOD the policies must span multiple jurisdictions and cover the areas of transportation, urban planning, and land-use. These policies must be aimed at reducing vehicle miles traveled while blustering transit ridership.

Thesis Supervisor: Fred Moavenzadeh

Title: James Mason Craft Professor of Civil and Environmental Engineering

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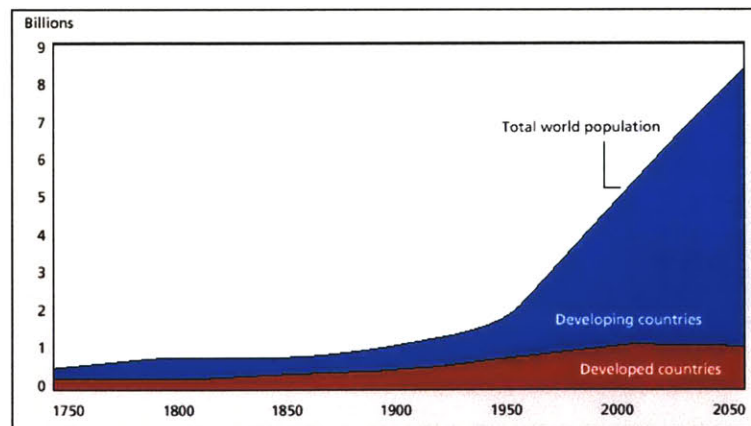
1 Sustainable Development and Energy Consumption in Urban Transportation: A Need for Comprehensive Solutions

“Efficient energy use is one of the main strategic measures not only for the conservation of fossil energy resources but also for abatement of air pollution and the slowing down of anthropogenic climate change. Accordingly, economic and technical measures to reduce specific energy demand should be priorities across all sectors of an economy.”

[Source: World Bank Group]¹

Energy is the corner stone of our modern industrial economy and is vital for almost all human activities. Energy is a critical factor in economic and social development, and no country has achieved significant development without access to energy services. From the 1900s to present the industrialized nations have consumed vastly more energy than the developing world. Yet now, as the developing world races to catch up, the picture is changing. The population of the developing countries is more than four times greater than that of the developed countries, yet the primary energy consumption of the developed countries is more than twice as great. Improvements in health care and agriculture are increasing life expectancy in the developing world and will have serious implications for population growth. By the year 2050 it is forecasted that the population of the developing countries will approximately double, while the population in developed countries will slightly decrease.

Figure 1: World Population, 1750-2050

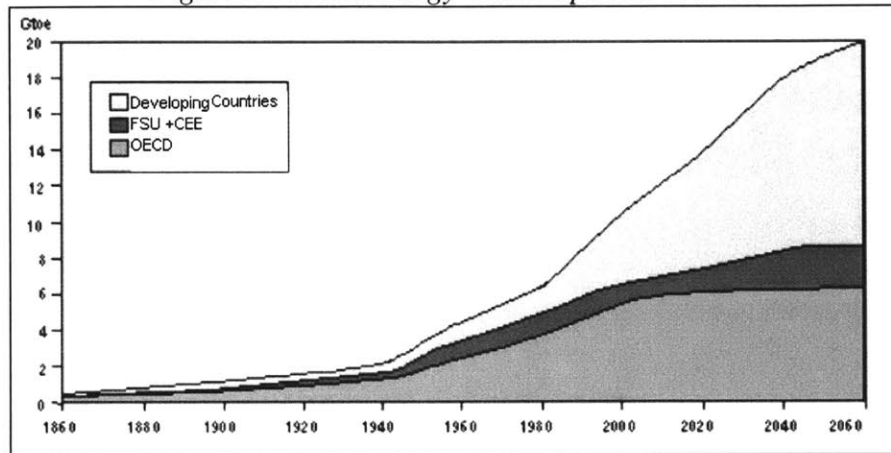


[Source: World Bank]²

¹ Pollution Prevention and Abatement Handbook, World Bank Group (1998). *Efficient Use of Energy*

New technologies and technology transfer will not only increase the availability and dependence on energy services in developing countries, but will also create new demand. This dramatic population growth coupled with rapidly increasing demand for energy will drastically change the distribution of energy consumption. Assuming that energy demand in developing countries grows by 2.6 percent per year, their total consumption will be double the level of total consumption in industrial countries by 2050.³

Figure 2: World Energy Consumption Forecast



[Source: FAO]⁴

While the growth in energy consumption in developing countries will have a positive effect on reducing poverty, the environmental consequences will be vast. CO₂ emissions are one of the leading causes of global warming, and emissions of CO₂ correlate directly to energy consumption. Yet, developing countries have the opportunity to do things differently from what was done in the past. Through technology transfer and lessons learned from the industrialized nations, the developing countries can follow a more sustainable path.

² World Bank, (2002). *Beyond Economic Growth, Meeting the Challenges of Global Development*. www.worldbank.org/depweb/beyond/global/

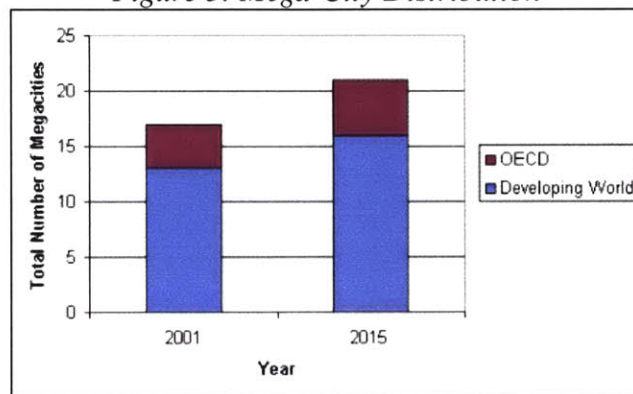
³ Food and Agriculture Organization of the United Nations. *Environment and Natural Resources Working Paper No. 4*. www.fao.org

⁴ Ibid

1.1 Mega-City Context

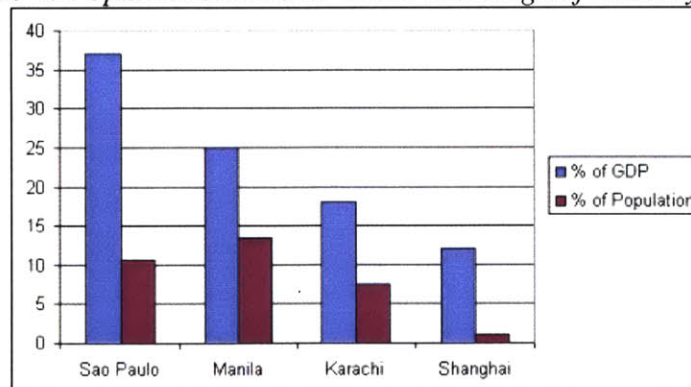
Mega-cities are the centers of population, economy, culture and political power. Yet, along with these characteristics, they are also the greatest source of energy consumption, resource depletion, and pollution. In order for developing countries to take a more sustainable development path, they must address their growing demand for energy and strive to find solutions to reduce their demand and increase their efficiency. Mega-cities stand out as natural targets for such solutions given their extreme population and waste generation. Solutions aimed at Mega-cities are most likely to have the scale and scope necessary to provide the step-change that is needed to alter their current development pattern.

Figure 3: Mega-City Distribution



[Source: Haghseta]⁵

Figure 4: Population and GNP as a Percentage of Country Total



[Source: Haghseta]⁶

⁵ Haghseta, Farnaz (2002). *AGS Workshop on Mega-Cities of the 21st Century*

⁶ Ibid

1.2 Sustainability and Energy Consumption

While energy consumption is critical to economic and social development, it also is the leading source of pollution and a major contributor to natural resource depletion. As such, improvements in energy efficiency are one of the most important steps we can take towards sustainable development. Energy consumption takes place throughout all economic sectors, and throughout all aspects of our daily lives. The widespread use of energy creates infinite possibilities and applications for improving energy efficiency. In the past, much focus and research has been conducted on improving the energy efficiency of sub-systems, such as: automobile efficiency; efficiency in housing; infrastructure efficiency, and so on. While these improvements are necessary, and have a positive impact on the environment, they lack the scope and impact that are necessary to create a sustainable development path. Focusing on one sub-system, independent of the system in which it interacts, will offer limited benefits that may be nullified by the total system behavior.

For example: Take the automobile as a sub-system. When only focusing on the sub-system, the logical conclusion is: improving the efficiency of the automobile engine directly correlates to less emissions and improved air quality. Yet when we consider the larger system in which the automobile interacts, urban and suburban road networks, this conclusion is not so straightforward. In Los Angeles, drivers are faced with worsening congestion and urban sprawl; improvements in automobile efficiency have been insufficient to cope with increased vehicle miles traveled, and longer commute times. Furthermore, increasing automobile efficiency reduces travel costs and increases the vehicle miles traveled by some drivers. The improvements of automobile efficiency are necessary, but to deal with the larger problem of fuel consumption and pollution we need a more comprehensive approach.

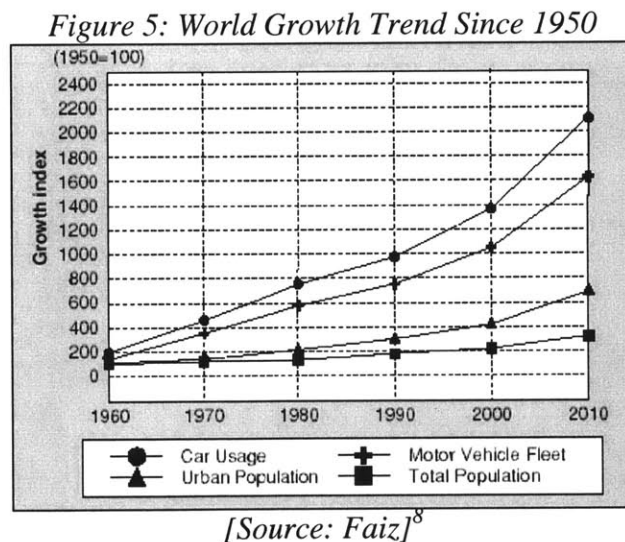
In order to make our cities more sustainable we must focus on the interaction of these sub-systems. It is not enough to look just to technology for solutions to sustainable

energy consumption; we must also incorporate comprehensive institutions, policies and planning.

1.3 Problem Statement

Transportation is one of the major sources of energy demand and serves as a good example of how a comprehensive systems approach can be utilized to greatly reduce energy consumption.

In the year 2000, 43 percent of the energy consumed worldwide came from oil. Of this 43 percent, 58 percent was used for transportation. This concludes that 25 percent of world energy consumption was spent on transportation. This large percentage is due to the growing dependence on the automobile in both developed and developing countries. Since 1950, the world's vehicle fleet has grown more than tenfold, and is expected to double within the next twenty years. The growth rate of the global vehicle fleet is greater than that of both urban and total population. Much of this growth is expected to occur in Eastern Europe and developing countries.⁷

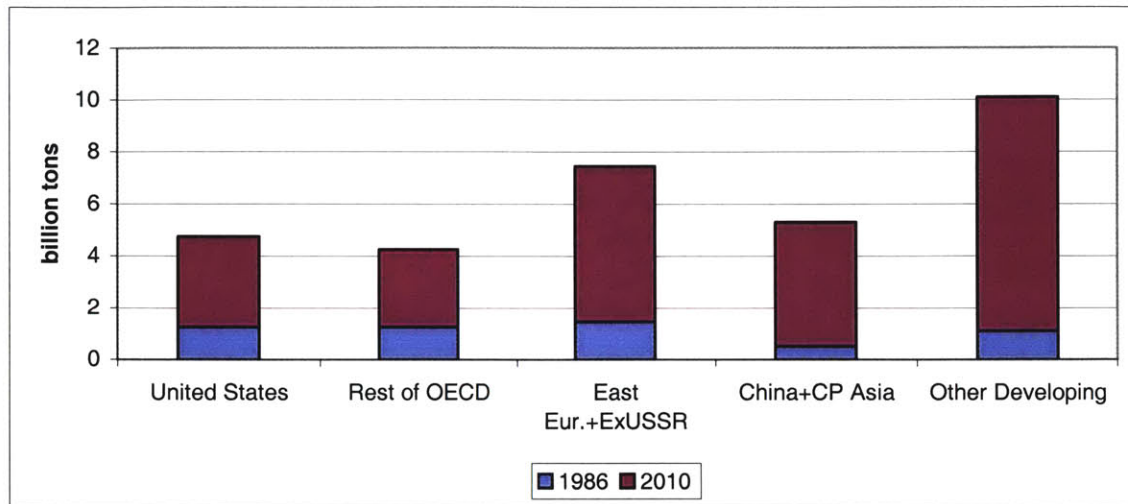


⁷ Bose, Ranjan. *Automobiles and Environmental Sustainability: Issues and Options for Developing Countries*. www.teriin.org/division/padiv/uts/docs/ft01.pdf

⁸ Faiz, (1993). *Automotive Emissions in Developing Countries – Relative Implications for Global Warming, Acidification, and Urban Air Quality*.

The growth of the motor vehicle fleet in the developing world will have a significant impact on the distribution of fuel consumption and correspondingly a significant impact on CO₂ emissions. It is projected that in the year 2010 the developing world will produce three times as much CO₂ emission as the OECD countries.

Figure 6: CO₂ Emissions in a Rapidly Changing World Scenario

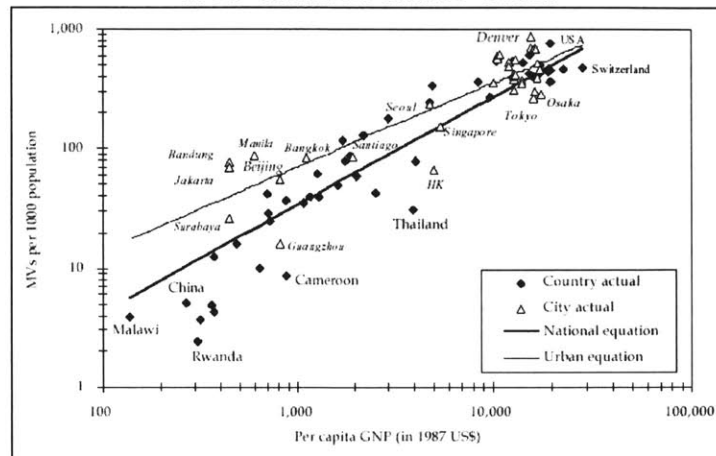


[Source: Faiz]⁹

Growth of the automobile fleet and growth of the per capita income have a linear relationship. As the developing countries industrialize and the per capita income increases, the vehicle fleet will steadily grow. Yet, the relationship of per capita income and population density is not linear. As the per capita income increases, the population density tends to decrease. As the per capita income rises, so does the size of the vehicle fleet, which increases the likelihood of urban sprawl and de-densification. The linkage of urban sprawl and automobile dependence creates a negative cycle. Simply put: as the vehicle fleet increases the cities begin to sprawl, the automobile becomes more necessary, which creates a greater demand for road infrastructure, which then leads to more sprawl.

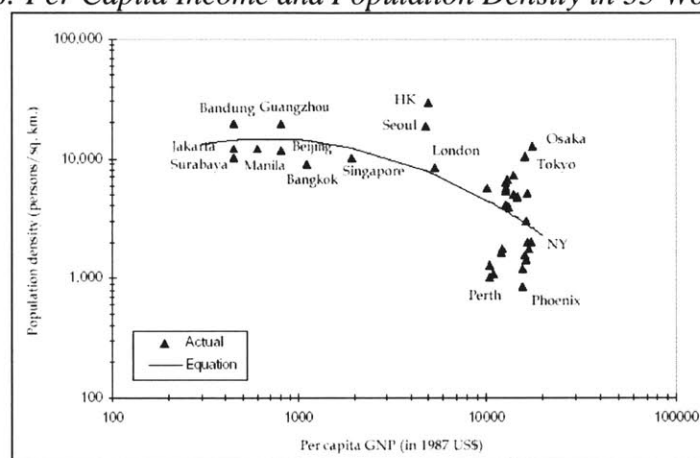
⁹ Faiz, (1993). *Automotive Emissions in Developing Countries – Relative Implications for Global Warming, Acidification, and Urban Air Quality*.

Figure 7: Per Capita Income and Motor Vehicle Ownership in 50 Countries and 35 Cities



[Source: Ingram & Liu]¹⁰

Figure 8: Per Capita Income and Population Density in 35 World Cities



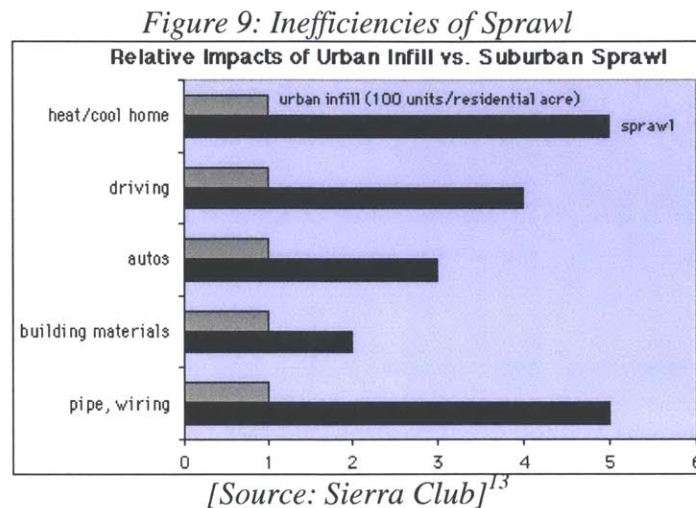
[Source: Ingram & Liu]¹¹

Urban sprawl is a major source of energy inefficiency. Not only does it lead to more vehicle miles travels, more fuel consumption, more air pollution, but also to inefficiencies in infrastructure provision. De-densification of residential and commercial districts causes an increase in both energy services and materials. It is estimated that sprawl development uses five times more pipe and wire, five times as much heating and cooling energy, twice as many building materials, three times more automobiles, and

¹⁰ Ingram & Liu, (1999). *Determinates of Motorization and Road Provision*. World Bank.

¹¹ Ibid

causes four times as much driving. It also consumes 35 times as much land, and requires 15 times as much pavement as compact urban living.¹²



1.4 Sub-Systems Approach

The problems that arise from a growing vehicle fleet – congestion, pollution, sprawl, resource depletion, etc. – have been the focus of many researchers, planners, and politicians. There have been many attempts to curb these problems through innovative technologies, strategic planning, and prescriptive and restrictive policies, yet for the most part these solutions have all been focused on a single aspect of the problem. The focus has been on sub-systems and the solutions generally lack the scope and scale to provide the desired outcome.

Examples of Sub-system approaches in transportation:

Mexico City: “Hoy No Circula” Program¹⁴

Mexico city is on of the most polluted and congested Mega-cities in the world. The air pollution within the city is a major problem; dangerous levels have been reached and sustained by certain pollutants, in particular ozone (O₃), and particles (TSP). One of the

¹² Sierra Club. *The Costs of Sprawl*. www.sierraclub.org/sprawl/community/costs.asp

¹³ Ibid

¹⁴ Leautaud & Perez-Barnes, (1997). *Energy and Infrastructure Policies for Mitigation of Air Pollution in Mexico City*. Massachusetts Institute of Technology.

most visible strategies aimed at reducing air pollution was “Hoy No Circula,” or “Day without a Car.” The program was aimed at reducing the number of vehicles within the city by banning each car from driving a specific day per week. The aim was to reduce congestion and pollution through reduced vehicle miles travels and increased public transportation ridership and carpooling. While this policy seems intuitive based on a sub-systems view, when viewed in a larger system, the policy was inequitable and unsuccessful. It was unfair because wealthier citizens could easily avoid it by simply purchasing a second car. The program was counterproductive because ownership of a second car tended to increase driving, and the second cars were often used-vehicles that were significantly old, and had lower technical standards. These cars had increased emissions based on less efficient combustion technology. The failure of this program suggests that a more comprehensive solution is needed to address a dynamic problem of this magnitude.

Parking restriction¹⁵

Parking restriction is another method that has been used to reduce the number vehicles within the city center. Viewed as a sub-system, it is logical that if you restrict the number of spaces, the number of vehicles will also be reduced. When Mexico city applied this approach by reducing the number of parking spaces within the city center, conditions only worsened. Vehicles began “double parking,” which effectively reduced the capacity of the road networks. Vehicles also spent more time circling within the city looking for parking. This in turn increased congestion and pollution. This policy had the complete opposite result than was intended.

Segregated Bus Lanes

Another sub-system strategy employed to reduce congestion on major thoroughfares is segregated bus lanes or High Occupancy Vehicle (HOV) lanes. These are methods used

¹⁵ Cheatham, Benjamin (2002). *Sustainable Urban Transportation in Developing Mega-Cities: A Review of Policies, Regulations, and Technologies*. Massachusetts Institute of Technology.

by governments to reallocate road supply from single occupant vehicles (SOV) to more densely populated travel modes. The concept is to increase the number of passengers utilizing the existing supply without increasing the infrastructure capacity or number of vehicles. There are many problems with this limited reasoning. First, many drivers are unwilling to give up their automobile for public transportation. By reducing the road supply for SOV, congestion is greatly increased on the remaining supply. Secondly, if the HOV lanes do free-up additional road space for SOV vehicles, the net effect may be to increase the total number of vehicles using the road. Both of these results would have the negative impacts of increased air and noise pollution.

1.5 Comprehensive Solution

Each of the three examples clearly demonstrates that simply focusing on one aspect of the problem cannot produce a significant impact or provide the desired benefits. The causes of congestion and air pollution are multi-faceted dynamic problems that need to be addressed with a systems approach. In order to provide long-term sustainable solutions we must focus on the interaction of the sub-systems that contribute to, and govern the problem.

We have already discussed the role of energy consumption and transportation, as well as several sub-system solutions that were aimed at reducing transportation energy consumption and the negative externalities associated with this consumption. Next we will propose one solution to this problem that attempts to take a systems approach: Transit Oriented Development (TOD).

2 Transit Oriented Development

2.1 Conceptual Overview

In its most basic sense Transit Oriented Development (TOD) is a method of locating people near public transportation to reduce their dependence on the automobile. TOD is a unique development approach that incorporates aspects of Smart Growth, New Urbanism, and Location Efficient Development. It brings together ideas from urban planning, transportation, and market economics.¹⁶

“Transit Oriented Development is moderate to higher-density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment and shopping opportunities designed for pedestrians without excluding the auto. TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use.”

[Source: Cal Trans]¹⁷

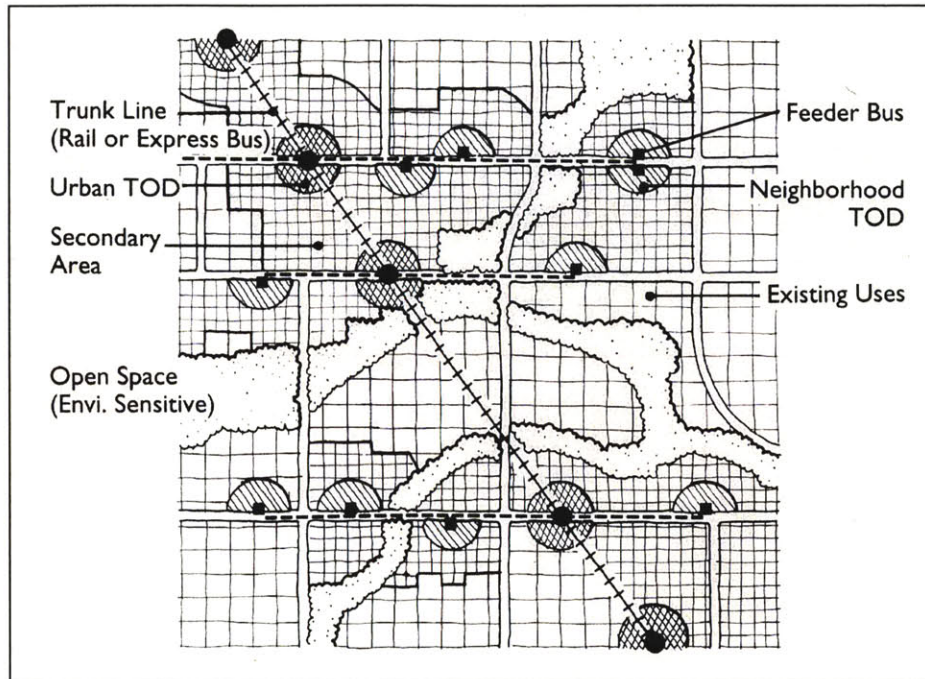
The TOD model includes regional and local planning. The backbone of the TOD is the regional Trunk Line that can be either heavy rail, light rail, or express bus. Along the Trunk Line are a series of Urban TODs, which are developed at high commercial and residential densities. Neighborhood TODs are composed of residential uses and local serving-shopping, and are linked to the urban transit stations via feeder bus lines.¹⁸ It is not enough for a development to be adjacent to transit; it must be shaped by transit, in terms of parking, density, and building orientation.

¹⁶ Bernick & Cervero, (1997). *Transit Villages in the 21st Century*

¹⁷ California Department of Transportation, (2002). *Statewide Transit-Oriented Development Study*

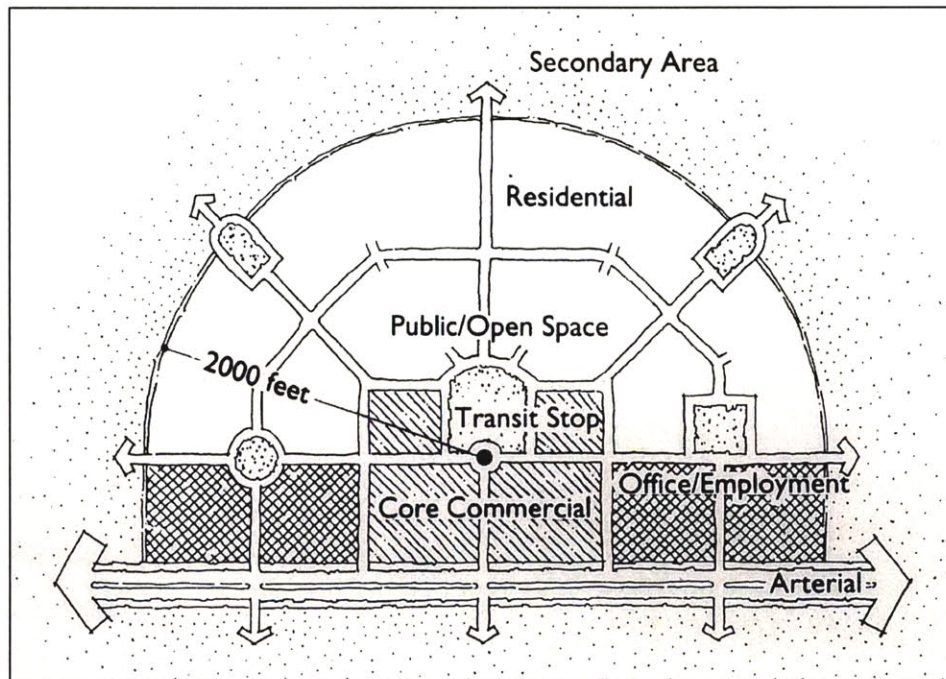
¹⁸ Peter Calthorpe Associates, (1990). *Transit-Oriented Development Design Guidelines for the County of Sacramento*

Figure 10: Regional TOD Model



[Source: Calthorpe]¹⁹

Figure 11: Local TOD Model



[Source: Calthorpe]²⁰

¹⁹ Calthorpe, (1993). *The Next American Metropolis: ecology, community, and the American dream.*

2.2 Elements of a Transit Oriented Development

Beyond the basic improvement of transportation a TOD should offer a number of other benefits to the public. The objective is to offer pleasant, lively communities that provide a wide range of transportation choices and help to alleviate the negative impacts of sprawl. Each of the elements - enhanced mobility, environmental quality, pedestrian friendliness, alternative suburban living and working environments, neighborhood revitalization, public safety, and public education - is critical to the long-term success of a TOD.²¹

2.2.1 *Enhanced Mobility and Environment*

Because of their pedestrian focus, higher density, mix of land uses, and proximity to transit, TODs increase the amount of trips made by transit, bicycling, and walking. The access to transit also improves the mobility options for children, the elderly, and non-drivers. As more auto trips are converted to transit trips, the congestion along the transit corridor is often improved. Reduced congestion and vehicle miles traveled (VMT) also lead to less air pollution.

2.2.2 *Pedestrian Friendliness*

True to its definition, a TOD is pedestrian oriented. The streets are narrower and lined with trees and lights. The sidewalks are wide, and the buildings come out to the sidewalk. There are less parking lots and parking is moved to the back of buildings, and on-street parallel parking. The mix of residential and commercial uses provides a diverse environment where walking is encouraged, and friendly encounters are increased. Health is improved as walking trips become regular, and auto pollution is decreased.

²⁰ Calthorpe, (1993). *The Next American Metropolis: ecology, community, and the American dream.*

²¹ Bernick & Cervero, (1997). *Transit Villages in the 21st Century*

2.2.3 Alternative Suburban Working and Living Environments

A TOD offers residents the opportunity to live in the suburbs without losing much of the convenience associated with living in the city, such as services and entertainment. The proximity to transit provides commuters with a quick, reliable, and comfortable ride to work, without being dependent on the auto. TODs provide an increase in affordable housing without contributing to sprawl. They also provide a “24-hour” activity pattern that some residents and businesses value.

2.2.4 Neighborhood Revitalization

A TOD can provide an economic boost to inner-city regions. These neighborhoods are often overlooked by developers and in need of major repair. Adding a transit node to these communities serves as a catalyst for development. The foot traffic generated by station users invites retailers to develop along the street, and the access to transportation and jobs creates a demand for housing. As well as new development, infill development often occurs further reinforcing the revitalization of the neighborhood.

2.2.5 Public Safety

The ability of a TOD to provide a safe atmosphere for its residents is crucial to its long-term success. Safety is a critical factor to attract new residents to the neighborhood. The safety of the central areas are improved by providing a mix of uses that create a busy streetscape both in the day and at night. The safety is further improved by increased human interaction which creates a heightened sense of community.

2.2.6 Public Celebration

It is important to make the transit station a gateway to the neighborhood. It should be a public gathering spot, and community center. This can be accomplished by providing public places around the station such as parks and plazas. These public spaces should be

programmed with uses that attract activity from morning to night. Successful programming includes farmers markets, food vendors, and kiosks. The public spaces can also be used for concerts, performances, and demonstrations.

2.3 Historical Evolution

2.3.1 Streetcar Suburbs

Towards the end of the 19th century and in the beginning of the 20th century rail transit networks began to grow in many of the United States larger cities and suburbs. These networks had a profound effect on the American city, they not only spread the city boundaries, but they created a new paradigm of living in the suburbs and working in the city. America's railroad suburbs laid out a new pattern of community settlement, housing, and transportation.²² Most often, a single owner built the streetcar lines and their surrounding neighborhoods. The owner built the transit to add value to the residential development by providing transportation from the homes to the jobs in the city center. Since private developers built the railroads to serve their development, the term "development-oriented transit" is more appropriate than TOD.²³ These developers also provided small retail clusters at the transit stops to additionally serve both the residents and commuters. In many ways these streetcar suburbs of the turn of the century are the precursor for the modern TOD, yet it was not until a long period of automobile dominance that we would return to this model.

2.3.2 Auto-Oriented Suburbs

The streetcar suburbs of the early 20th century were soon to be forgotten as the American love for the automobile took hold. In the 1920s and 1930s automobile usage saw explosive growth, and began to transform the suburban landscape. The suburbs grew

²² Bernick & Cervero, (1997). *Transit Villages in the 21st Century*

²³ Belzer & Autler, (2002). *Transit Oriented Development: Moving From Rhetoric To Reality*. The Brookings Institution Center on Urban and Metropolitan Policy and The Great American Station Foundation

from compact neighborhoods focused on a transit line, to sprawling neighborhoods where the majority of houses were far from a rail station. The post-World War II period saw a further decline of transit usage and greater movement towards freeway suburbs. Many rail systems were abandoned or dismantled. The predominant mode of transit shifted from rail to buses. The bus system was not segregated from the automobile and hence was subject to the same congestion and inefficiencies. Unlike the streetcars of the past, in most cases the bus system had little or no impact on the land-use patterns.²⁴

2.3.3 Present Situation

As the streets become increasingly congested, and the environment increasingly polluted, the need for alternative modes of transportation is apparent. Within the last decade a number of subtle but promising trends have emerged that are working to counteract these problems: the growth of transit ridership, increased transit investment, frustration with congestion and urban sprawl, the new urbanism and smart growth movements, and greater support and recognition of the advantages of TOD.²⁵ Taking a look at TODs around the United States shows that there is significant effort being made, but most are still falling short of their potential.

2.4 Features of a Transit Oriented Development²⁶

2.4.1 Mixing Complementary Transit Supportive Uses

For a TOD to be successful it must provide a mix of complementary uses that enliven the neighborhood. A good mix of housing, offices, entertainment, education, retail and services will provide continuous daily activity and offer consumers increased options, and pedestrians a safer environment. Providing incentives for ground level shops, offices, and services can also increase the pedestrian activity. Cultural and civic

²⁴Belzer & Autler, (2002). *Transit Oriented Development: Moving From Rhetoric To Reality*. The Brookings Institution Center on Urban and Metropolitan Policy and The Great American Station Foundation

²⁵ Ibid

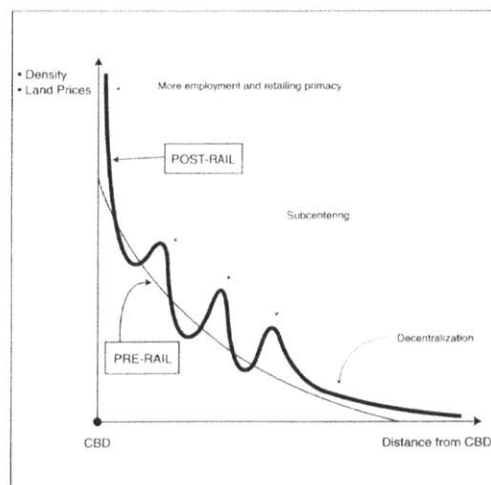
²⁶ TOD. *Bringing transit to your community*. <http://www.rtd-denver.com>

functions such as libraries, museums and theaters serve as destination centers that attract significant foot traffic.

2.4.2 Compact Development

The highest level of density should occur at the transit station, this density should gradually decrease as you move outwards. This pattern of development creates a sense of city center. The most dense area should contain the majority of the commercial development, this creates an economic center. In the United States the recommended minimum densities for new residential development within a quarter of a mile from the station are 25-30 dwelling units per acre or greater. Between a quarter and a half of a mile, there should be a minimum of 15 dwelling units per acre.²⁷ Within a quarter mile of the station mixed-use buildings should have a floor-to-area ratio (FAR) of 0.75 minimum, and between a quarter and half mile the FAR should be 0.5 minimum. Figure XX shows the relationship of density to the distance from the Central Business District (CBD). The highest density occurs at the CBD, and then decreases as the radial distance increases. The density peaks are due to stations located outside the CBD.

Figure 12: Density in relation to distance from CBD



[Source: Cervero]²⁸

²⁷ TOD. *Bringing transit to your community*. <http://www.rtd-denver.com>

²⁸ Cervero, Robert (1998). *The Transit Metropolis, A global Inquiry*.

2.4.3 Pedestrian and Bicycle System

A significant goal of the TOD is to improve pedestrian access. This is done by creating an extensive network of pedestrian walkways that are efficient, comfortable, and safe. This includes building wide sidewalks on both sides of the street that can handle large groups, as well as providing areas for outdoor eating, shopping and sitting. The bicycle and pedestrian paths should lead to the transit station and connect far back into the surrounding neighborhood. Buffers should be created along the streets to separate the pedestrians from auto traffic. These can include planters, trees, public art, and on-street parallel parking. It is also important to provide signs that clearly label bicycle and pedestrian areas, as well as providing orientation. Bike racks, and lockers at the station, as well as bike racks throughout the city center encourage bicycle use.

2.4.4 Street Network

The street network should be interconnected, and composed of blocks between 200 and 400 feet long. The use of grid-through streets as opposed to traditional cul-de-sacs improves efficiency, reduces congestion, improves route options, and decreases travel distances for drivers and pedestrians. Traffic calming features such as speed bumps, stop signs, and cross walks should be added to reduce driving speeds and improve safety. The streets should be designed to handle multiple modes of transportation including pedestrians, bicycles, buses, and cars.

2.4.5 Parking

Parking should be regulated within the city. A maximum number of parking spots should be determined, and at grade parking lots should be discouraged. Structured and underground parking, as well as on-street parking should be maximized. Shared parking lots can be provided for uses that relate to different times of the day, such as a movie theater and a shopping center.

2.4.6 *Site Design and Building Orientation*

There are a number of design and planning features that make a TOD more pedestrian oriented. Buildings should front on the streets and have minimal setbacks. The buildings should have windows and doors faced towards the sidewalk, not just blank walls. Parking should be placed behind the buildings so it does not create a void in the block. Parking structures should be built with a façade to obscure their functionality and incorporate them into their surroundings. Loading docks and dumpsters and other unattractive elements should be placed in the back of the building, or out of sight. Buildings should be individual in nature and have varied architectural features and materials. The zoning should require a minimum development density, not a maximum.

2.4.7 *Streetscape*

The streetscape should be designed to the human scale. This means providing trees, lighting, benches, planters, and art that people can relate to. By providing “outdoor rooms” along the streets, a sense of place is created, and people are more likely to walk along these corridors.²⁹ Unsightly items, such as large billboards should not be allowed, and utilities should be placed underground when possible.

2.4.8 *Community Spaces*

It is important to create open spaces near the transit station. Parks, plazas, and gardens all serve to keep the station active throughout the day. The open spaces should be programmed with celebrations, parades and performances. Placing these facilities near the transit station promotes its use and attractiveness.

²⁹ Cervero, Robert (1998). *The Transit Metropolis, A global Inquiry*.

2.5 Impacts

2.5.1 Economic Impacts

The economic impacts of a TOD can be numerous. Some of the most notable benefits are increased real estate values, reduced infrastructure spending, reduced transportation externalities, and economic development stimulation.

“TOD can be a focus of economic investments, so that scarce funds are used efficiently and effectively. By offering viable transportation alternatives for workers, TODs can help to reduce the amount of time that some workers spend in traffic, and also help to reduce congestion-related business costs. Furthermore, TOD can increase business opportunities, and can be used as a tool to create distinctive, marketable communities with higher property values and tax revenues.”

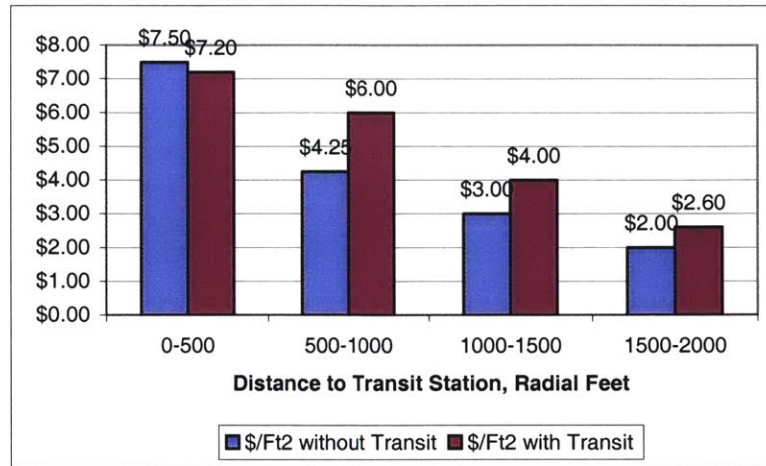
[Source: Cal Trans]³⁰

As a result of the improved land values, many TOD project can be funded through “value capture” strategies. This is accomplished through additional tax revenue, or a Local Improvement District (LID) tax assessment in specific areas. The high-density urban centers associated with TODs can also provide accessibility and agglomeration economies.³¹ Other economic benefits can be found through co-development, leasing sites near the station, and leasing space in the station or on the vehicles for advertisement.

³⁰ California Department of Transportation, (2002). *Statewide Transit-Oriented Development Study*

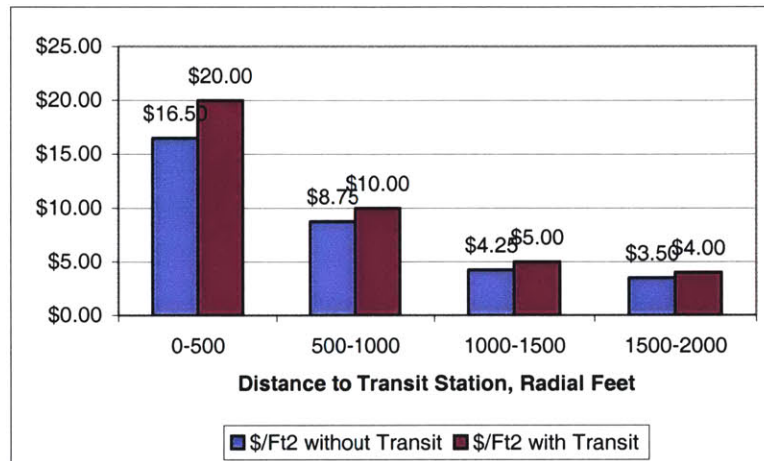
³¹ TOD. *Using Public Transit to Create More Accessible and Livable Neighborhoods*.
www.vtpi.org/tdm/tdm45.htm

Figure 13: Average Residential Land Values by Distance to Transit Station



[Source: Cervero]³²

Figure 14: Average Commercial Rents by Distance to Transit Station



[Source: Cervero]³³

2.5.2 Social Impacts

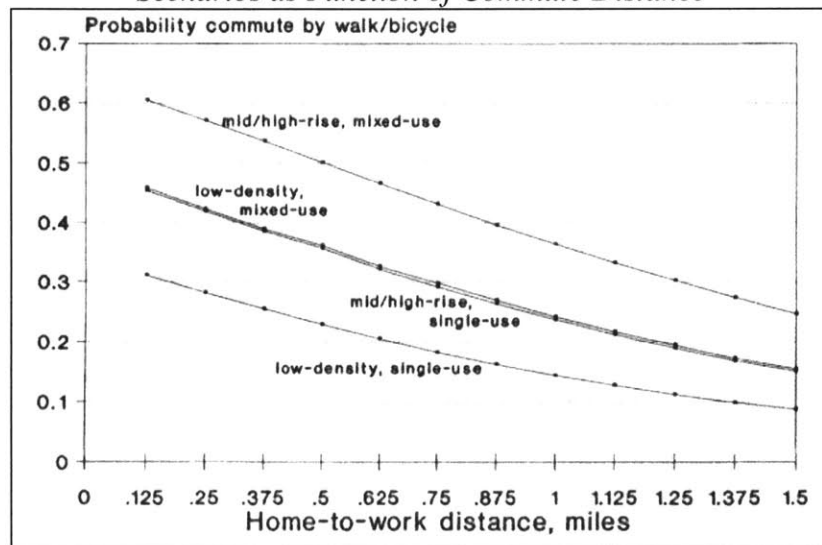
One of the key benefits of a TOD is the general improvement of mobility, and transportation choices for non-drivers. Transit offers more freedom of mobility for

³² Cervero, (1997). *Transit-Induced Accessibility and Agglomeration Benefits: A Land Market Evaluation*. University of California, Institute of Urban and Regional Development.

³³ Ibid

children, the disabled, the elderly, and for those who cannot afford an automobile. Another benefit of the TOD is the high-density and assortment of housing. The broad range of housing close to the transit station accommodates a range of income levels and offers more pricing variation than the typical single family home. Providing a variety of housing types from affordable to luxurious creates a diverse residential population. This residential diversity coupled with the pedestrian friendliness of a TOD creates an enhanced sense of community. The general health of the residents is also increased through increased walking trips and improved air quality.

Figure 15: Probability of Commuting by Walking or Bicycling for Four Land-Use Scenarios as Function of Commute Distance



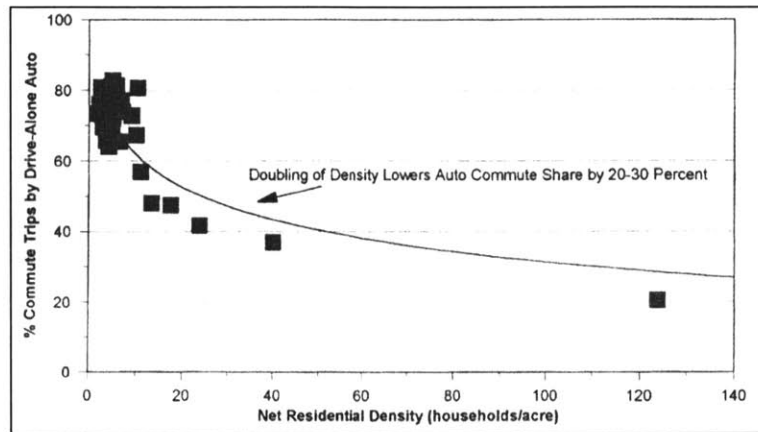
[Source: Bernick & Cervero]³⁴

2.5.3 Environmental Impacts

By shifting the development pattern from typical suburban densities to compact urban nodes many environmental impacts result. As reliance on the automobile decreases, there is a reduction of vehicle miles traveled which results in less congestion and less pollution. The higher density development reduces use of open space and restricts urban sprawl. Reduced road infrastructure decreases the amount of surface runoff and improves water quality.

³⁴ Bernick & Cervero, (1997). Transit Villages in the 21st Century.

Figure 16: Effect of Increased Density on Driving Patterns



[Source: Bernick & Cervero]³⁵

2.6 Implementation

2.6.1 Land Use Planning and Zoning³⁶

A TOD should be organized to provide a variety of uses within a compact area that accommodates walkable connections between the uses. This approach requires planning at a small scale and paying attention to the buildings, streets and blocks. The planning should also look for opportunities to infill, enhance the public areas, and improve mobility and security. Central to the theme of TOD, the zoning must accommodate for both a vertical and horizontal mix of uses. One strategy that has proven effective is the use of Overlay Zones. These zones define the boundaries for targeted TODs, and should also address the clustering of uses, the vertical mixing of uses within a single building, and the placement of public and private uses. The Overlay Zone should also provide guidelines for the relationship of buildings to the street, and open spaces to the buildings and streets. The zoning should be “prescriptive,” rather than “restrictive” to define appropriate land uses to strategic locations, while allowing for flexibility. The zoning should also include foresight to accommodate for expansion, and insure that it occurs in a planned fashion. The New Urbanism approach uses a master plan in parallel to project-specific codes. The role of the master plan is to proscribe land use locations, and

³⁵ Bernick & Cervero, (1997). *Transit Villages in the 21st Century*.

³⁶ ULI Advisory Services, (1995). *The New Green Line Chicago, Illinois*

densities at the lot, street and block level. The project-specific codes are much more detailed in nature and address elements of the development. These are more architectural and design-based and focus on elements such as front, rear and side yards; parkways; open spaces; and street features. The purpose of the codes is to make sure the new developments create a “sense of place” without inhibiting creativity or individuality. There is also the opportunity to provide zoning related incentives that both encourage and define the goals of the TOD. Incentives can come in the form of density bonuses, reduced parking requirements, and increased maximum FAR.

2.6.2 *Empowerment Zone*³⁷

The federal Empowerment Zone established in 1993, is based on the belief that both the residents and businesses of a community can work together to create jobs and opportunities in impoverished communities. Many of the benefits of the Empowerment Zone support the same goals of a TOD. They both rely on the collaboration of neighborhoods, businesses and government to achieve sustainable communities. The Empowerment Zone specifies a targeted area for revitalization. This zone then receives tax credits and tax-exempt bond financing to induce development. The strategy involves increasing residential population and employment opportunities concurrently. Providing transit within the Empowerment Zones provides further incentives for development and is complementary to its goals. For this relationship to be achieved it must be planned in conjunction with and integrated into the Empowerment Zone.

2.6.3 *Development and Redevelopment Programs*³⁸

While zoning incentives and tax benefits will work to induce development in some locations, this will not be effective in all areas. For this reason it is imperative for the government or city to employ economic development and redevelopment programs. These programs should promote TOD and strive to improve physical linkages and

³⁷ History of the Federal Empowerment Zone. www.ci.minneapolis.mn.us/citywork/ez/history.asp

³⁸ ULI Advisory Services, (1995). *The New Green Line Chicago, Illinois*

intermodal transit connections. They should look to leverage transit in a comprehensive manner, hence reducing the chances of scattered investments. The program can include using long-term tax abatements to promote residential and commercial development and redevelopment in TOD zones.

The redevelopment program can be specifically useful for housing rehabilitation. Blighted buildings will have a negative effect on infill development within neighborhoods. Deteriorating building must be located and receive the proper financial support to be rehabilitated. Preserving and restoring the fabric of the community will serve to attract new residential and commercial developers.

2.6.4 Land Assembly and Control

As part of a “value capture” strategy the city must aggressively assemble key and contiguous parcels of land within the targeted TOD zone. This must be done early in the planning process and the land must then be available for TOD related projects shortly after. The city land should be managed as a portfolio and not on a parcel-by-parcel basis.

2.6.5 Expedited Permitting³⁹

An oversight committee should be created that has the authority to expedite permitting and entitlement. Private developers are looking to minimize total time to complete their projects, and any streamlining process would add value to their developments. The flexibility of an Empowerment Zone could be leveraged to enable such an oversight committee.

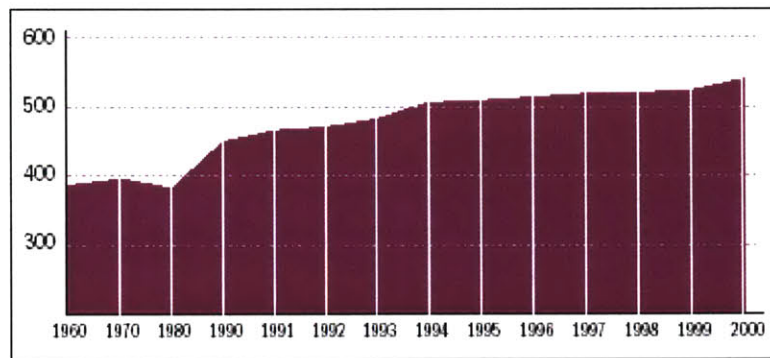
³⁹ Ibid

3 Lessons Learned

3.1 Portland Oregon: MAX Light Rail System

Portland is the largest city in Oregon with a metropolitan population of 1.8 million, and a population of 529,121 within the city. For the last 15 years the population growth rate has averaged 2.2 percent, and the population is projected to grow by approximately 27 percent over the next 20 years.⁴⁰

Figure 17: Portland City Population, 1980-2000



[Source: COPOOT]⁴¹

Portland lies within the Tri-County Metropolitan Transportation District (Tri-Met), which includes parts of three counties in the Portland area: Multnomah, Washington, and Clackamas. The city of Portland has an area of 144.9 square miles, while the metropolitan area covers 3,725 square miles. Portland is the center of commerce for the metropolitan area; it is surrounded by a large and diverse manufacturing economy. The port of Portland handles the third largest volume on the West Coast. Portland's largest three employment sectors are services, trade and manufacturing which account for 29, 24, and 15 percent of the total employment respectively.⁴² Portland's manufacturing

⁴⁰ City of Portland Office of Transportation, (2002). *Facts About Portland, Transportation Options*. www.trans.ci.portland.or.us/

⁴¹ Ibid

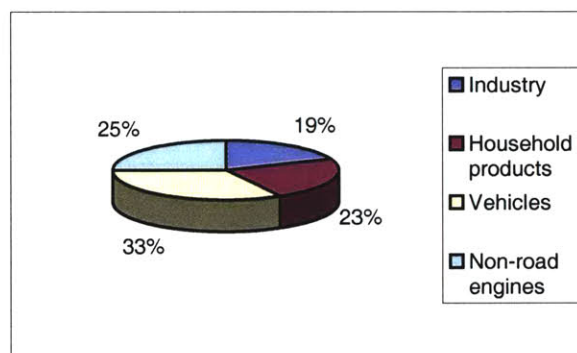
⁴² Ibid

mainstays are metals, instruments, machinery and electrical equipment. The value of property in the metropolitan area has steadily increased for the past ten years, as well as income levels. Portland is home to many international corporations; two of the most well known are Nike and Intel. Portland's booming economy, mild climate, and scenic environment make the city ideal location for residents, businesses, and tourists.

3.1.1 Context⁴³

Within the last 30 years Portland has made significant steps to reduce the air pollution in the region. From 1972 to 1985, the number of carbon monoxide violations dropped from 100 to 0, and remained at zero ever since. Portland was the first city in the United States to adopt a carbon dioxide reduction plan. This plan will establish a 10 percent CO₂ reduction by the year 2010. The main pollution sources within the region come from vehicles, non-road engines, household and other products, and industry. The air pollution source percentage breakdown is shown in Figure 18.

Figure 18: Air Pollution Sources



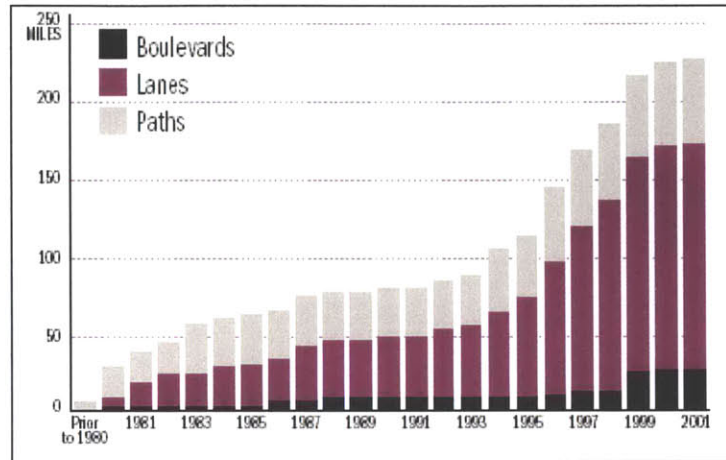
[Source: COPOOT]

Vehicles are the single highest contributor to air pollution, they account for 33 percent. From 1980 and 1999, Vehicle Miles Traveled (VMT) increased by 122 percent, while the regional population grew only by 38 percent. During this same period Portland has been

⁴³ City of Portland Office of Transportation, (2002). *Facts About Portland, Transportation Options*. www.trans.ci.portland.or.us/

working to counteract this trend by promoting transit and bicycling. Figure XX shows the growth of the bike network in Portland.

Figure 19: Bike Network Growth, 1980-2001



[Source: COPOOT]

3.1.2 Institutional Framework⁴⁴

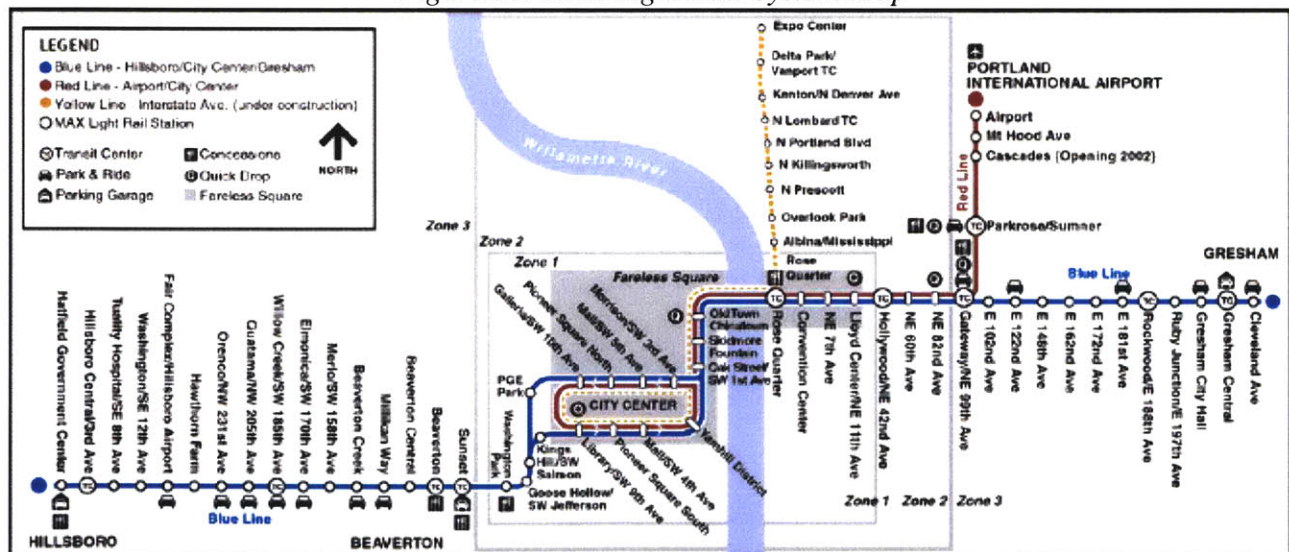
Tri-Met is a municipal corporation of the state of Oregon. It was created in 1969, by the Portland City Council, acting under special provisions granted by the Oregon State Legislature. At that time all operations of private transit companies were handed over to Tri-Met. Tri-Met is governed by a board of directors composed of seven members, who set agency policy, enact legislation, and review contracts. Tri-Met was given broad powers to provide mass transportation on behalf of the district, and can issue general obligation bonds, revenue bonds, and also has an employer payroll tax.

⁴⁴ Tri-Met MAX System Overview. www.tri-met.org

3.1.3 System Overview⁴⁵

Portland's light rail system is known as the Metropolitan Area Express (MAX). The MAX light rail system is composed of 38-miles of track that runs east and west through the city of Portland, and links the cities of Gresham, Beaverton, and Hillsboro. The 38-miles of track are split between two lines: The MAX Blue Line and the MAX Red Line. The Blue Line was built in two separate phases, Eastside MAX, and Westside MAX. Eastside MAX was opened in 1986, and stretches 15-miles from downtown Portland to Gresham. Westside MAX was opened 12-years later and passes through large pieces of undeveloped land; it stretches 18-miles from Portland to Hillsboro. The most recent addition to the system is the new Airport Red Line. This line was opened in 2001; it is 5.5-miles long and provides service to the Portland International Airport. There are also plans to build a 5.8-mile Interstate MAX that will connect the Expo Center to the rest of the MAX. Light rail is a key piece of the regionally integrated Tri-Met. Within the urbanized portion of the Tri-Met region there are 98 bus routes and eighty-four of these connect to the MAX at various stations.

Figure 20: MAX Light Rail System Map



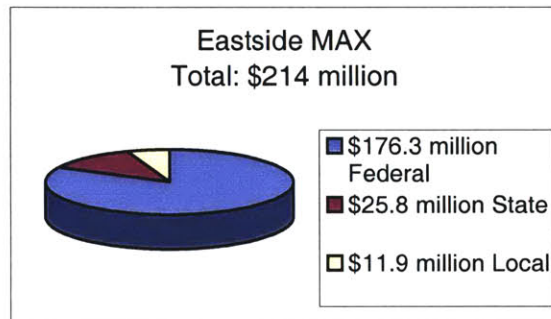
[Source: Tri-Met]

⁴⁵ Tri-Met MAX System Overview. www.tri-met.org

3.1.4 Infrastructure Spending

The Eastside MAX Blue Line was constructed from March 1982 to September 1986 and funded primarily through federal government dollars. Pursuant to their regional transportation plan, Tri-Met traded in funds for an urban freeway to invest in transit and smaller road projects. Of the total \$214 million price tag for the Eastside line, 82 percent came from the federal government, 12 percent came from state government, and 6 percent came from local government.

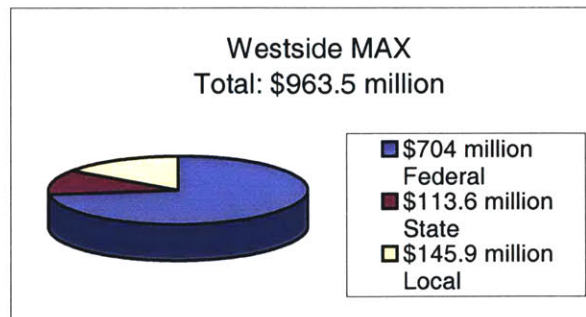
Figure 21: Sources of Funding for the MAX Blue Line (Eastside)



[Source: CFTE]⁴⁶

The Westside MAX Blue Line was constructed from July 1993 to September 1998 and received 73 percent of its funding from federal dollars, 12 percent from state dollars, and 15 percent from local dollars. Of the \$145.9 million local dollars raised for the Westside MAX, \$125 million came from the approval of property tax bonds.

Figure 22: Sources of Funding for the MAX Blue Line (Westside)



[Source: CFTE]⁴⁷

⁴⁶ Center for Transportation Excellence. *Transit Profile: The Portland area MAX light rail system.*
www.cfte.org/success/success.htm

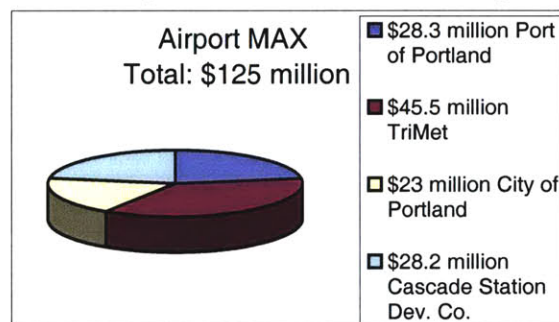
⁴⁷ Ibid

The Airport MAX Red Line was funded through an innovative public/private partnership. The key members were the Port of Portland, Tri-Met, the City of Portland, Portland Development Commission, and Bechtel Enterprises:

- The Port is making contributions from locally generated passenger fees dedicated to airport improvements
- Tri-Met is using general funds
- The City of Portland is contributing Airport Way Urban Renewal Funds that were managed by the Portland Development Commission
- Bechtel and Trammell Crow have formed the Cascade Station Development Company and will receive a long-term lease on 120-acres at Cascade Station for their investment

Of the total \$125 million to build the Airport line, Bechtel contributed \$28.2 million. In return for their investment, Bechtel, with partner Trammell Crow, have gained the rights to develop a 120-acre TOD at the airport entrance. The contributions of all parties can be seen in Figure XX.

Figure 23: Airport MAX Red Line Funding Sources



*[Source: Tri-Met]*⁴⁸

The Interstate MAX is scheduled to open in the fall of 2004 and has a total cost of \$350 million. The federal government will provide \$257.5 million, the City of Portland will provide \$30 million, Tri-Met will provide \$25 million, and regional transportation funds will provide the remaining \$37.5 million.⁴⁹

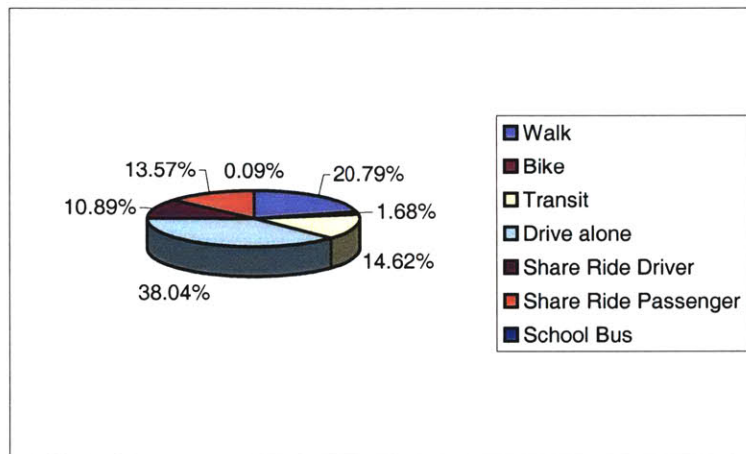
⁴⁸ Tri-Met MAX System Overview. www.tri-met.org

⁴⁹ Ibid

3.1.5 Ridership Statistics

Since 1980, transit as a modal split has increased by over 50 percent. In 1995, transit accounted for almost 15 percent of all trips taken in downtown Portland, while the private automobile accounted for 38 percent.⁵⁰

Figure 24: Downtown Portland Modal Split, 1995



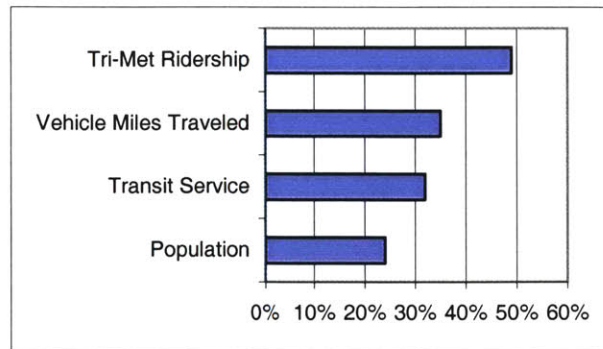
[Source: COPOOT]

Between 1990 and 2000 the transit ridership within Tri-Met grew 49 percent. Within this same period the transit ridership grew faster than vehicle miles traveled and population growth.⁵¹ The total transit ridership has grown for 13 consecutive years and provided more than 89 million trips in 2002.

⁵⁰ City of Portland Office of Transportation, (2002). *Facts About Portland, Transportation Options*. www.trans.ci.portland.or.us/

⁵¹ Tri-Met MAX System Overview. www.tri-met.org

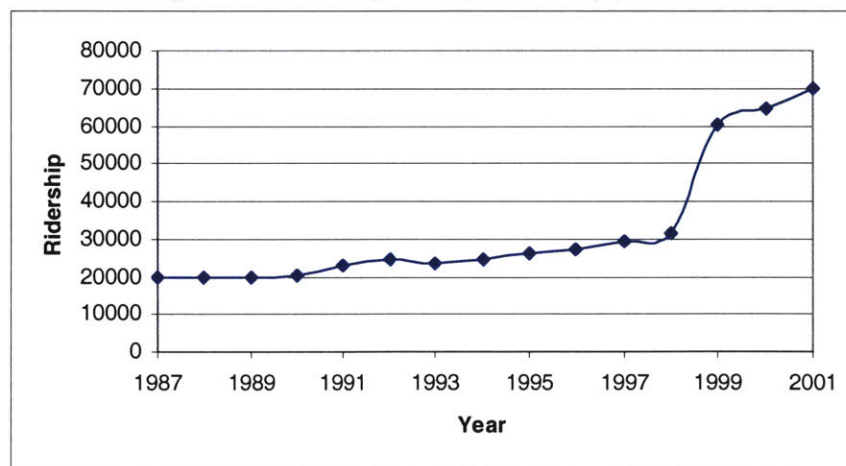
Figure 25: Comparative Growth Between 1990-2000



[Source: TriMet]⁵²

MAX has seen more than a tripling in ridership since it first opened in 1986. Much of this growth was spurred by the opening of the Westside MAX in 1998, which increased the average daily ridership almost 100 percent. In 2002 MAX had a daily average of 78,000 weekday trips, which was 12 percent higher than in 2001. The weekends also saw growth with an average of 59,600 Saturday trips, and 42,100 Sunday trips. MAX accounts for approximately 25 percent of all Tri-Met's weekly riders

Figure 26: Average Daily Ridership for MAX



[Source: CFTE]⁵³

3.1.6 Benefits⁵⁴

⁵² Tri-Met MAX System Overview. www.tri-met.org

⁵³ Center for Transportation Excellence. *Transit Profile: The Portland are MAX light rail system.* www.cfte.org/success/success.htm

⁵⁴ Ibid

Overall the MAX Light Rail system has been a huge success. The improvement of basic mobility has been achieved by connecting neighborhoods with major employment centers, regional shopping and entertainment facilities. The MAX has deferred the need for new highways; downtown Portland has not increase the road capacity in 25 years. While livability and quality of life are difficult to measure Portland has been the recipient of numerous awards in this area, including following: No. 1 Choice of Best Places to Live in 2000 (Money Magazine), Presidential Award for Design Excellence 2001 (President Clinton), Design for Transportation National Award 2000 (US Department of Transportation). For many Portland residents the MAX has become the preferred mode of travel. Most people who ride Tri-Met do so by choice, 83 percent of the riders either have a car and choose not to use it, or choose not to own a car and ride Tri-Met. This has had a positive effect on the environment. In 2001 Tri-Met eliminated 65-million car trips, which translates into reduced air emissions of 4.2 tons daily. By the year 2015 it is projected that the light rail network will reduce air pollution by 1,700 tons yearly. The MAX has also proven to be a catalyst for TOD. Since the opening of the MAX in 1986, there has been over \$2.9 billion in new development within walking distance of its 54 train stations. The impact of the MAX on real estate values has also been favorable. A single family home next to a rail station on the MAX Eastside Line commands a ten percent premium over one 1,000 feet away from the station.

3.1.7 Policies

The success of MAX is primarily due to the strategic linkage of transportation investment and land-use planning. Central to this theme was the development of an Urban Growth Boundary (UGB) that legally defines the limitations of the urban and rural areas. This boundary encloses 235,000 acres that has increased only by 3 percent since its inception in 1979.⁵⁵ Transit stations and corridors were planned to be located in the center of activity. This placement along with increased density and height limitations allowed transit to define the neighborhoods. These two broad strategies coupled with numerous

⁵⁵ G.B. Arrington, (1996). *Beyond the Field of Dreams: Light Rail and Growth Management in Portland*.

local requirements both bolstered transit ridership and improved the livability of the city. Some of the local policies include: requiring development to occur at a pedestrian scale with a mix of uses - blank walls are illegal, buildings must come right up to the sidewalk, and 60 percent of ground floor uses must be retail; limiting commuter parking - downtown offices have parking maximums, and parking is increasingly limited the closer you are to MAX; providing free transit downtown - a “Fareless Square” was created to improve mobility in the downtown area and to promote transit ridership.

3.1.8 Lessons Learned

The MAX light rail system has been publicized as the most successful TOD project in the United States. This success is largely due to the foresight and strategic planning of TriMet. By linking land-use planning and transit development they took the initiative to clearly define growth boundaries and transportation corridors. The process of establishing long-term goals and plans was achieved well before construction began. Implementation was also streamlined by rezoning the station areas for higher densities and mixed-uses prior to station development. Another key to the success of the MAX was support of the public and the support of private developers. This support was gained by including elected officials, developers, and citizens, across jurisdictional boundaries, in the decision making process.

3.2 Washington D.C.: Metrorail

Washington, DC, is the capital of the United States. It is one of the few planned cities in the United States, and was designed to imitate the metropolitan centers of Europe with its grand boulevards, abundant parks, and magnificent architecture. Its many monuments, and art museums attract millions of tourists annually. The federal government and tourism are the mainstays of the city's economy, and many unions, business, professional, and nonprofit organizations are headquartered there. Washington DC relies on much of its economic activity from the public sector. Approximately 21 percent of federal, state and local government employees reside within Washington DC metropolitan area. Services employ another 40 percent.⁵⁶

3.2.1 *Institutional Framework*

The Washington Metropolitan Area Transit Authority (WMATA) was created in 1967, to develop, build, finance and operate a regional transportation system in the Nations Capital. It provides service for a population of 3.4 million, and covers approximately 1,500 square-miles.⁵⁷ WMATA was formed through an interstate compact with the District of Columbia, the state of Maryland, and the commonwealth of Virginia. It serves a number of transit zones including: the District of Columbia, the suburban Maryland counties of Montgomery and Prince George's and the Northern Virginia counties of Arlington, Fairfax and Loudoun and the cities of Alexandria, and Falls Church. WMATA operates the second largest rail transit system in the United States, and the fifth largest bus network.⁵⁸ Today WMATA provides transportation for over a third of federal government workers, and millions of tourists. WMATA is governed by a board of directors who are responsible for setting policies and overseeing budgeting, operations, development, expansion, safety and procurement. The environment in which WMATA operates is very complex given the number of authorities that have influence over it: 1) state and local governments, that subject WMATA to a number of laws and regulations;

⁵⁶ The Economist. www.economist.com

⁵⁷ WMATA Facts. <http://www.wmata.com/about/metrofacts.pdf>

⁵⁸ Ibid

2) the Tri-State oversight committee, which is responsible for safety oversight and review; 3) the National Capital Regional Transportation Planning Board of the Metropolitan Washington Council of Governments, which develops long and short term plans to guide WMATAs capital investments; 4) the Federal Transit Administration, which provides broad oversight; 5) and the National Transportation Safety Board, which is responsible for accident investigation on transit as well as other modes of transportation.⁵⁹

3.2.2 System Overview

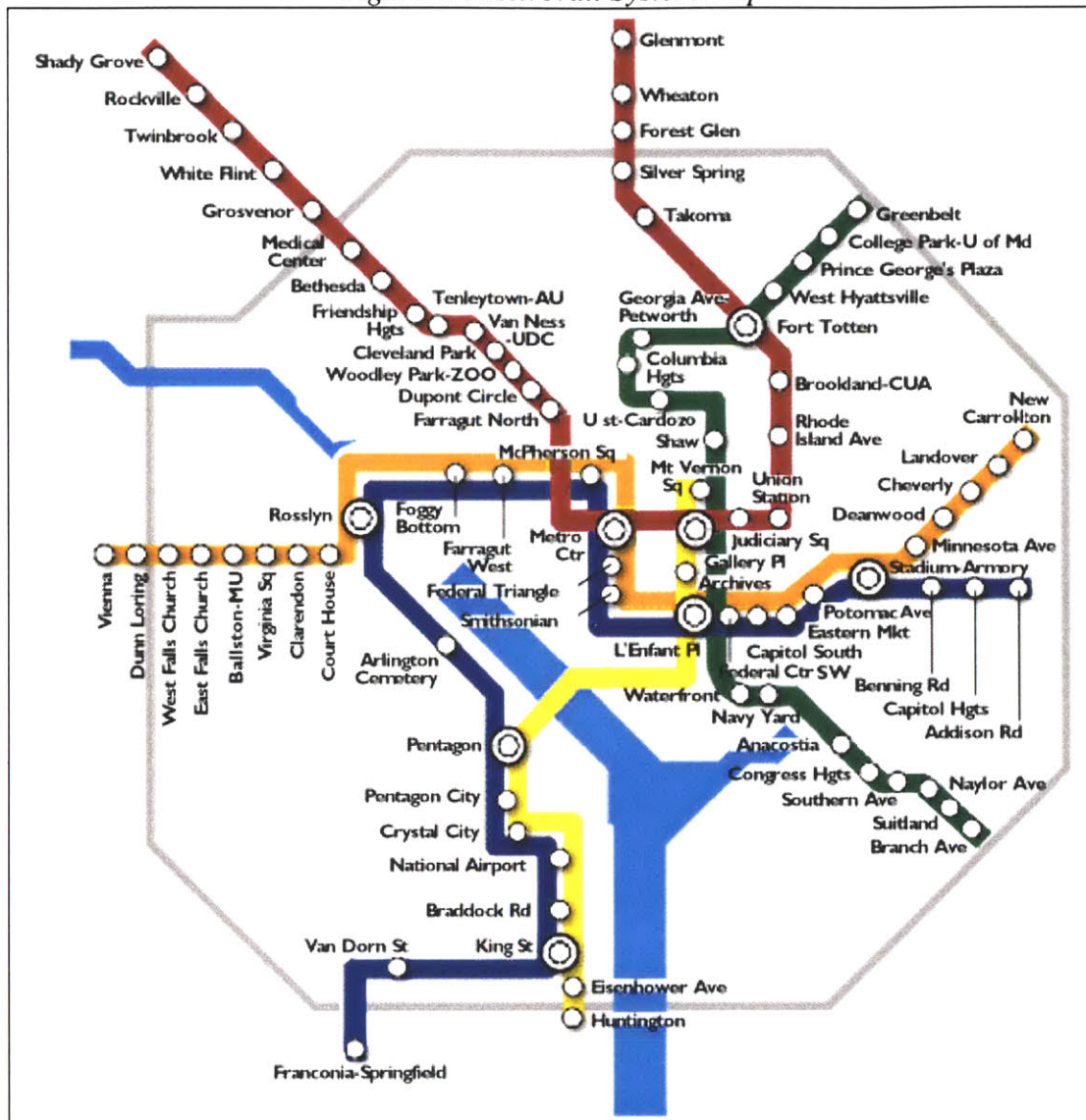
WMATAs heavy rail network is most commonly referred to as the Metrorail. This extensive system consists of 103-miles of rail, and 83 stations: approximately 50-miles of subsurface rail, 44-miles of surface rail, and 9-miles of arterial rail; 47 subsurface stations, 31 surface stations, and 5 arterial stations. The Metrorail network is composed of four diametric lines, which connect the outlying suburbs to the downtown area, and one radial line that serves the downtown and southern corridor. The rail network is divided into five lines, which are color-coded: Red, Blue, Orange, Green, and Yellow. The Red Line is a single independent line; the Blue and Orange Line share a joint trunk, as do the Yellow and Green Lines.⁶⁰ Metrorail's rolling stock consists of a total 762 cars, which operate in four and six-car trains, and have a capacity of approximately 110 standing passengers per car. WMATA has plans to expand the system to 106.6-miles and 86 stations by 2004. As well as operating the Metrorail, WMATA is also responsible for the Metrobus. The Metrobus operates 1,443 vehicles on 348 routes and 164 lines.⁶¹

⁵⁹ Hecker, (2001). Mass Transit, *WMATA Is Addressing Many Challenges, but Capital Planning Could Be Improved*

⁶⁰ Vuchic & Casello, (2002). *Washington Metro: Planning for Growth*

⁶¹ WMATA Facts. <http://www.wmata.com/about/metrofacts.pdf>

Figure 27: Metrorail System Map



[Source: WMATA]

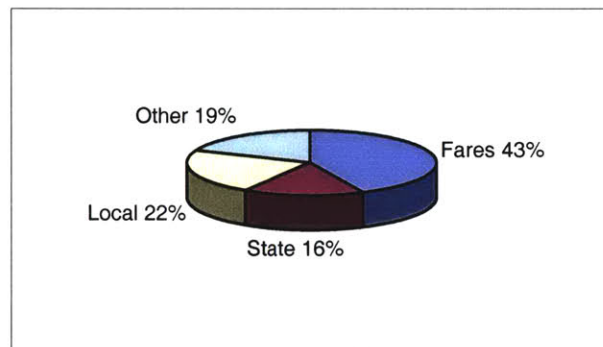
3.2.3 Infrastructure and Operations Spending

The 103-mile Metrorail cost \$9.4 billion to construct, and as such is the most expensive completed public works project in U.S. history.⁶² Unlike most of the nations transit systems, WMATA does not receive dedicated sources of tax revenues. Based on their unique relationship, the federal government and the Metro are partners in transportation. Approximately half of the Metrorail stations serve federal facilities, and 36 percent of

⁶² Washington's Magnificent Metro. www.railwayage.com/sept01/washmetro.html

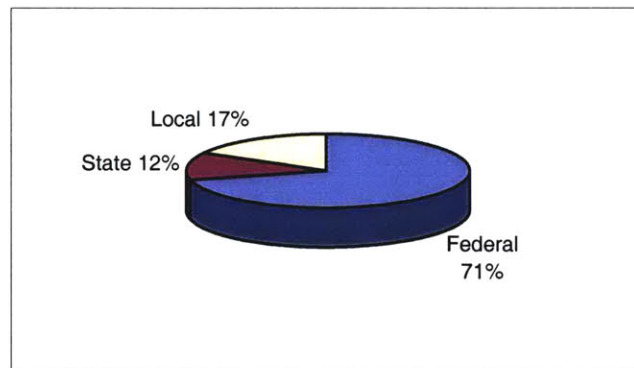
local federal employees rely on the Metro for transportation to and from work. WMATA receives grants from the federal government and annual contributions from each of the local jurisdictions it serves. In 2001, the annual operations and maintenance expenses of Metrorail and Metro Bus combined to equal \$803 million. Of these expenses, 43 percent are funded through fares, 16 percent are funded through the state government, 22 percent are funded through local governments, and 19 percent come from other sources. For the same year the capital funds expended were \$425 million. Of these, 71 percent were funded through the federal government, 12 percent were funded through state government, and 17 percent were funded through local governments.

Figure 28: Sources of Operating Funds Expended, 2001



[Source: NTD]⁶³

Figure 29: Sources of Capital Funds Expended, 2001



[Source: NTD]⁶⁴

In 2002 the total revenue from passengers was \$290 million, while the total operating revenue was \$320 million. The passenger revenue is based on a zoned fare system; \$1.10

⁶³ National Transit Database, (2001). *Washington Metropolitan Area Transit Authority (WMATA)*

⁶⁴ Ibid

for up to the first 3-miles, and a maximum fare of \$3.25. The average fare in 2002 was \$1.56. The passenger revenues were still not enough to cover the total operating expenses; in 2002 the total operating net expense was \$457 million. To account for the difference, the Metrorail had to receive \$137 million in assistance. This assistance translates into an operating subsidy of \$0.74 per passenger. Approximately 63.5 percent of operating costs are recovered from fair revenue, while approximately 70.0 percent are recovered from total operating revenue

Figure 30: Operating Statistics and Ratios for FY 1997-2002

	1997	1998	1999	2000	2001	2002
STATISTICS						
Total Railcar Miles (000s)	43,408	48,790	50,394	51,298	56,399	64,890
Revenue Railcar Miles (000s)	41,988	47,190	48,794	49,698	54,799	63,290
Total Passengers (000s)	144,052	151,284	155,103	163,274	166,002	186,211
Total Passenger Revenue (000s)	\$225,973	\$242,129	\$247,992	\$256,833	\$253,442	\$290,421
Total Operating Revenue (000s)	\$244,469	\$262,025	\$273,629	\$283,927	\$281,551	\$320,270
Total Operating Net Expenses (000s)	\$337,512	\$353,509	\$367,470	\$392,056	\$406,742	\$457,294
Total Operating Assistance (000s)	\$93,043	\$91,484	\$93,841	\$108,129	\$125,191	\$137,024
RATIOS						
Passengers Per Revenue Railcar Mile	3.43	3.21	3.18	3.29	3.03	2.94
Operating Costs Per Total Railcar Mile	\$7.78	\$7.25	\$7.29	\$7.64	\$7.21	\$7.05
Operating Costs Per Passenger	\$2.34	\$2.34	\$2.37	\$2.40	\$2.45	\$2.46
Operating Subsidy Per Passenger	\$0.65	\$0.60	\$0.61	\$0.66	\$0.75	\$0.74
Average Passenger Fare	\$1.57	\$1.60	\$1.60	\$1.57	\$1.53	\$1.56
Percentage of Operating Costs Recovered from Passenger Revenues	67.0%	68.5%	67.5%	65.5%	62.3%	63.5%
Percentage of Operating Costs Recovered from All Operating Revenues	72.4%	74.1%	74.5%	72.4%	69.2%	70.0%

[Source: WMATA]⁶⁵

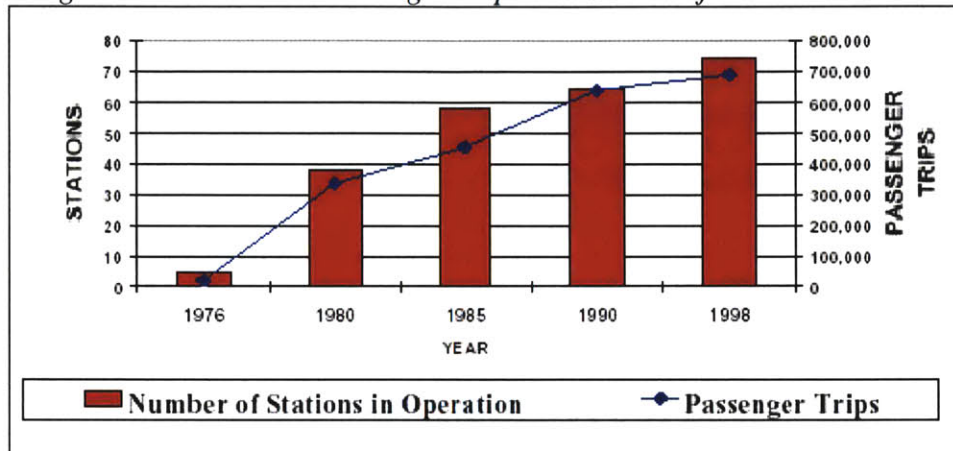
3.2.4 Ridership Statistics

WMATA has the second highest transit ridership in the United States, second only to New York City. In 2001 Metrorail provided 177 million passenger trips, and this number is expected to reach 186 million in 2002. Metrorail and Metrobus provide more than 1.1 million passenger trips on an average weekday. Approximately 18 percent of all peak trips made are by transit, and about 40 percent of all commuter trips to the urban center

⁶⁵ WMATA, (2002). *Annual Report and Budget Book*

are carried by Metro.⁶⁶ Since the original Metrorail segment opened in 1976, the number of daily riders has grown from approximately 50,000 to almost 700,000 in 1998. Figure 31 shows the growth in ridership compared to the growth of the rail system (number of stations built).

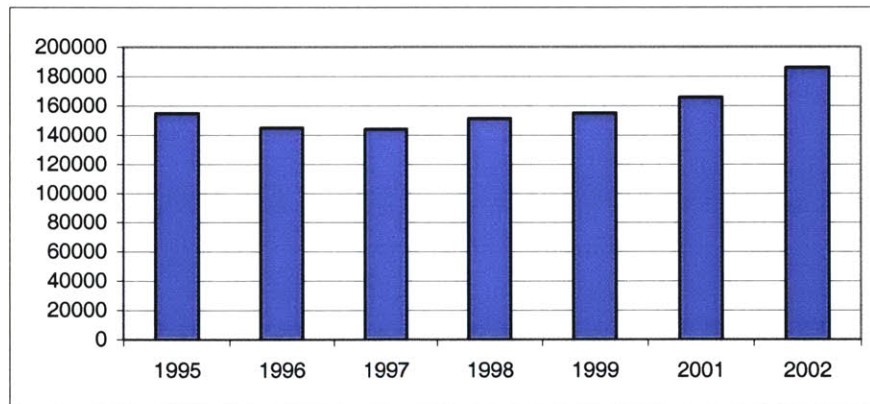
Figure 31: Growth in Passenger Trips and Stations from 1976 to 1998



[Source: FTA]⁶⁷

In 2001 Metrorail reached its highest annual ridership ever, carrying 174,268,000 passengers. During this same year the Metrobus reached its second highest annual ridership, carrying 145,340,000 passengers.⁶⁸

Figure 32: Metrorail Annual Ridership FY 1995-2002



[Source: WMATA]⁶⁹

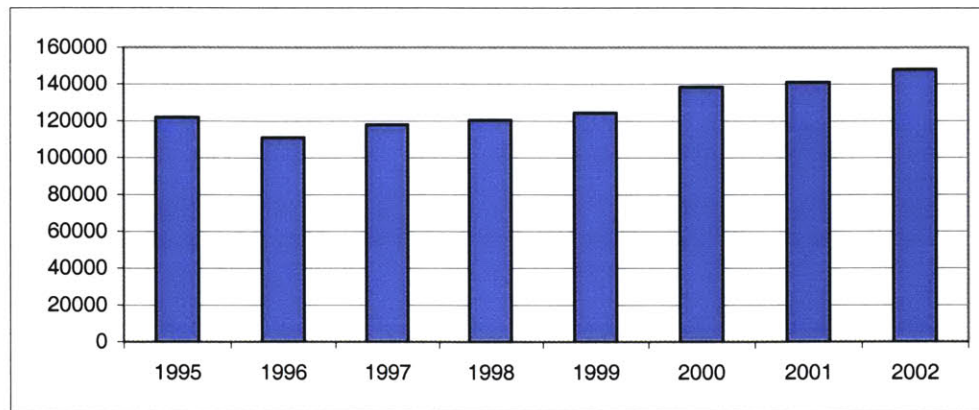
⁶⁶ Center for Transportation Excellence. *Transit Profile: The Washington Metropolitan Area Transit Authority (WMATA)*. www.cfte.org/images/success_washington.pdf

⁶⁷ Federal Transit Administration, (1998). *Completion of the Metrorail System, Washington DC*

⁶⁸ Metro Press Release, (2001). www.wmata.com/about/MET_NEWS

⁶⁹ WMATA, (2002). *Annual Report and Budget Book*

Figure 33: Metrobus Annual Ridership FY 1995-2001



[Source: WMATA]⁷⁰

3.2.5 Benefits

The Metrorail has had a profound positive impact on both the economic viability and the livability of the region. It has been a key factor in facilitating regional economic growth by providing mobility and accessibility for the region. It has proven to be a catalyst for new development; the Urban Land Institute estimated that \$20 billion in additional development has been generated by the Metrorail.⁷¹ In Virginia alone, between 1994 and 2002, it is estimated that Metrorail will generate \$2.1 billion in tax revenues, and 91,000 jobs.⁷² Not only has the Metrorail spurred new development, but it has also shaped the development pattern and reduced the impacts of urban sprawl. In Maryland and Virginia many new suburban centers have been created around rail stations. Between 1980 and 1990, 40 percent of the regions newly constructed office and retail space was built within walking distance of a Metrorail station, and since 1990, 20 percent has been built close to a station.⁷³ The Metrorail has also had a distinct impact on the travel behavior of the regions residents. WMATA has achieved the second highest transit ridership in the United States, and the Metrorail has generated higher ridership than the bus system. Combined, the Metrorail and Metrobus remove 300,000 vehicles from the regions road

⁷⁰ WMATA, (2002). *Annual Report and Budget Book*

⁷¹ Washington's Magnificent Metro. www.railwayage.com/sept01/washmetro.html

⁷² WMATA, (2002). *Annual Report and Budget Book*

⁷³ Center for Transportation Excellence. *Transit Profile: The Washington Metropolitan Area Transit Authority (WMATA)*. www.cfte.org/images/success_washington.pdf

network daily. This reduction in auto supply results in eliminating the need for approximately 1,400 highway lane-miles. According to the American Public Transportation Association, the Metrorail and Metrobus have helped reduce hydrocarbon emissions by 1,400 tons, carbon monoxide by 9,000 tons, and nitrogen by 700 tons annually.⁷⁴ The Metrorail and Metrobus have improved the transportation choices for the regions residents, and improved their quality of life. The improvement of basic mobility has both unified the region and changed the image of the city. An analyst at KPMG estimated that the additional development generated by the Metrorail in the Commonwealth of Virginia is producing a 19 percent annual rate of return on their investment in the Metrorail.⁷⁵ Based on the success of the Metrorail and the growth rates of the region, WMATA expects to add an additional 150-miles of track by the year 2025, and see a doubling of ridership.

3.2.6 Policies

Much of the success of the Metrorail is due WMATA's Joint Development Program. This program was put in place in the early 1970s to promote projects that achieve the following goals:⁷⁶

- Promote TOD by giving priority to developments that follow smart growth principles; reduce dependence on the automobile; increase pedestrian/bicycle trips; foster safe communities; enhance the areas adjacent to the transit stations; include mixed-uses; provide active public places.
- Attract new transit riders through increased residential and commercial development on WMATA owned land or private properties that are adjacent to Metro stations.
- Generate a new stream of revenue to help maintain and operate the Metro through joint developments between WMATA and private developers.
- Provide financial assistance to the local WMATA jurisdictions through expanding the local property tax base and adding value to current properties.

The program is supported by a set of guidelines and policies. These regulations were set up to clearly define the goals of WMATA and facilitate expeditious negotiation between

⁷⁴ WMATA, (2002). *Annual Report and Budget Book*

⁷⁵ Ibid

⁷⁶ WMATA. *Joint Development Opportunities*. www.WMATA.com

the public and private sectors. To date WMATA has produce 56 individual, revenue-producing joint development projects. These projects have combined to provide over \$129 million in revenue for the Metro, and this number is expected to double in the next five years.⁷⁷ Robert Dunphy, Senior Fellow for Transportation at the Urban Land Institute further notes the success of this program:

“The Joint Development Program has allowed the transit agency to lead by example in creating some of the most visible and valuable new developments in the Washington region. The Board is to be congratulated for its consistent vision and success in developing real estate projects that added riders and built better communities.”

3.2.7 Lessons Learned

The Metrorail has been highly successful at both generating ridership, and attracting revenues through private development. This success is due in part to the “sense of place” created by the Metrorail’s designers. The Washington Metrorail is well known as the most attractive subway system in the United States. While it is difficult to correlate the ridership to the attractiveness of the design, the architecture of the stations elevates the status of the Metrorail for local residents, and attracts tourists from around the globe. The station design has helped to gain the overall public support for the Metrorail, and this served to integrate the communities and rejuvenate the city.

The public support for the Metrorail has led to a demand for development around stations. The WMATA Joint Development Program has been beneficial in setting the guidelines for public/private partnerships. The guideline clearly states the goals of the public sector, and sets a standard for development projects. The guidelines also explain upfront the process the private developer must undertake, and the relationship between the two parties. These guidelines have been effective in building projects the public sector supports, generating additional revenues for the Metrorail, and revitalizing many communities.

⁷⁷ WMATA. *Joint Development Opportunities*. www.WMATA.com

3.3 Sao Paulo, Brazil: Metro

Sao Paulo is the capital of Brazil and the largest city in South America. It is Brazil's commercial, financial and industrial center and is home to the following industries: automobiles; textiles; processed foods; metal products; electrical equipment; pharmaceuticals; chemicals; furniture; and computers. The Sao Paulo Metropolitan Region (SPMR) covers 8,050 square kilometers, and has a population of 16.8 million. The SPMR is composed of over 39 individual municipalities of which Sao Paulo Municipality is the largest; it has a population of 8.5 million.⁷⁸ The SPMR is considered the most important economic region of Brazil and is responsible for generating approximately 50 percent of the Gross National Product (GNP)⁷⁹, 31 percent of the industrial domestic product, and 25 percent of the industrial labor force.⁸⁰

3.3.1 Context

Between the 1950s and the 1970s, Sao Paulo underwent a process of rapid industrialization. Much of this industrialization was spurred by a large injection of foreign capital, primarily in the automobile industry. At the same time Sao Paulo was experiencing extraordinary population growth, partially due to migration, which led to an accelerated growth of the urbanized areas.⁸¹ During this time, most of the government's transportation policies and investments supported the creation of new road infrastructure. This increase in road supply coupled with the growth of industrial wealth and population led to stimulation in private automobile ownership. In 1999 the vehicle population was estimated at 4.5 million cars, which is 25 percent of the national fleet. This number is increasing by 1000 cars every day.⁸² Additionally, 12,000 buses operate within Sao Paulo daily. This vast number of vehicles causes over 100 kilometers of roads to become

⁷⁸ World Bank, (2001). *Brazil – Sao Paulo Metro Line 4 Project*. Project Information Document

⁷⁹ World Bank Technical Paper NO. 373, (1997). *Vehicular Air Pollution: Experiences from Seven Latin American Urban Centers*

⁸⁰ Werna, (2000). *Combating Urban Inequalities, Challenges for Managing Cities in the Developing World*.

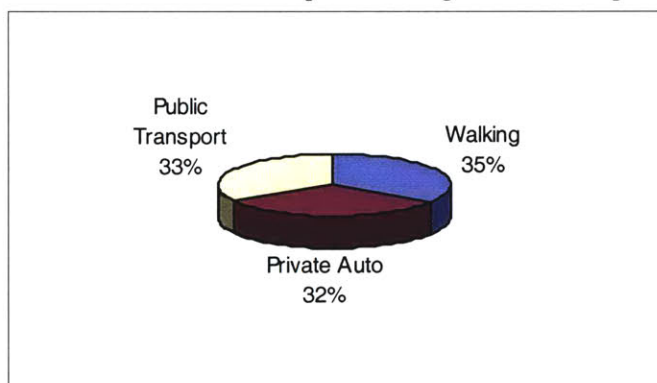
⁸¹ International Journal of Urban and regional Research, (2000). *The connectivity of infrastructure networks and the urban space of Sao Paulo in the 1990s*. Vol. 24, n 1.

⁸² Jacobi, Segura, & Kjellen, (1999). *Governmental responses to air pollution: summary of a study of the implementation of Rodizio in Sao Paul*. Environment and Urbanization, Vol. 11, No. 1, April 1999

congested at peak hours. The average traffic speed is 20 kilometers per hour, the occupancy rate is 1.5 persons per car, and it is estimated that 3.2 million cars circulate daily.⁸³

The rapid development and population growth has caused serious air and water pollution as well as overcrowding. Within the city, the air quality standards are often exceeded; the most recurring exceeded pollutants are suspended particulates, carbon monoxide, and ozone. Much of this pollution comes from the growing vehicle fleet and increased congestion. Automobiles account for 90 percent of the total air pollution within Sao Paulo.⁸⁴ Within the SPMR there are 31.4 million person trips daily: 10.8 million walking trips; 10.1 million private auto trips; and, 10.4 million public transportation trips.

Figure 34: Sao Paulo Metropolitan Region Modal Split 2001



[Source: World Bank PID]⁸⁵

Of the total 10.4 million public transportation trips, 76 percent were by bus, 2 percent were by vans, 16 percent were by the Metro, and 6 percent were by suburban trains. The low percentage of Metro trips is partly based on the poor integration of the Metro with the suburban train lines. Approximately 78 percent of Metro riders require one or more modal transfer, where as only 16 percent of bus trips require a mode switch.⁸⁶ This disconnect causes many potential rail riders to favor buses and cars which only lead to

⁸³ Jacobi, Segura, & Kjellen, (1999). *Governmental responses to air pollution: summary of a study of the implementation of Rodizio in Sao Paul*. Environment and Urbanization, Vol. 11, No. 1, April 1999

⁸⁴ Ibid

⁸⁵ World Bank, (2001). *Brazil – Sao Paulo Metro Line 4 Project*. Project Information Document

⁸⁶ Ibid

worsened congestion. Even with only 16 percent of the population traveling on Metro there is still considerable problems: 1) during peak travel times the Metro is overcrowded with greater than 8 passengers per square-meter; 2) travel from the metropolitan fringe to the urban centers can take up to 2.5 hours per day; 3) the cost of transportation fares is over a fifth of many individuals income.⁸⁷ Most of these problems are faced only by the urban poor, since the Metro is often looked at as a lower class mode of transportation by the upper and middle class. The percentage of Metro riders is also low because the system is very small; with only three lines it does not cover much of the urban areas.

3.3.2 *Institutional Framework*⁸⁸

Within the SPMR the transport sector is governed by two main bodies: 1) the Secretaria de Transportes Metropolitanos do Estado de Sao Paulo (STMSP); and 2) the Secretaria de Transportes da Prefeitura do Municipio de Sao Paulo (STM). The STMSP is responsible for the Sao Paulo Metro, the suburban railway and the metropolitan bus company. The metropolitan bus company operates all buses that travel between municipalities. STM is responsible for all the buses that operate within the Sao Paulo Municipality. Currently there is no regulatory agency in the SPMR at either the municipal or state level. The relationship and coordination between the SPMR and the STM is managed by the RTCC (Camaras Tematicas), but a more formal oversight committee could improve this relationship.

3.3.3 *System Overview*⁸⁹

The Sao Paulo Metro is owned by the State of Sao Paulo and is operated by the Companhia do Metropolitano de Sao Paulo. The system is composed of three lines, which have a total length of 49.2 kilometers. The first line (Blue) was operational in 1974 and provided service north and south between the city districts of Santana and Jabaquara through the central city area. The original length of the line was 16.7

⁸⁷ World Bank. (2001). *Project Appraisal Document For The Sao Paulo Metro Line 4 Project*

⁸⁸ Ibid

⁸⁹ Sao Paulo Metro. www.metro.sp.gov.br

kilometers, but this was extended to Tucuruvi in 1998. Line 1 is now 20.2 kilometers, and has 23 stations and 3 transfer stations. Line 1 provided service to 325 million passengers in 2001. The opening of Line 2 (Green) was delayed due to government changes and development problems on Line 3 (Red), and was not open for service until 1991. Line 2 provides service between Ana Rosa and Vila Madalena; this is the expanded area of Sao Paulo City, which contains a high concentration of financial institutions, state secretariats, radio and television broadcasting stations, theaters and museums. Line 2 is 7.0 kilometers, has 8 stations and 2 transfer stations, and provided service to 80 million passengers in 2001. Line 3 was opened in 1979 and was built taking advantage of railway bed from the former National Railway. Through rehabilitation and modernization of the Federal Railway the construction costs of Line 3 were reduced greatly. The total length of Line 3 is 22.0 kilometers; it has 18 stations and 1 transfer station, and provides service between Corinthians-Itaquera and Barra Funda. In 2001, Line 3 provided service to 310 million passengers.

The Metro is planning for the expansion of its current network, and has already begun construction on several lines:

- Metro Line 4 (Yellow) will connect the Luz district with the Vila Sonia district. This line will have a length of 12.8 kilometers, have 11 stations and will intersect the Blue, Green, and Red Lines. The projected demand is approximately 900 thousand passengers per day. It is expected to be completed in 2002.
- Metro Line 5 (Lilac) will be built in two phases; the first will have an expected daily demand of 320 thousand passengers per day. The length of the first phase will be 9.4 kilometers, and the total length will be 19.8 kilometers. One of the lines 17 stations will connect with the future Line 7.
- Metro Line 6 (Orange) will have a length of 29 kilometers and eight stations. This line is planned to serve approximately 500 thousand passengers per day. the orange line will operate in parallel to the Red line; one will provide express service and the other will make more frequent stops.
- Metro Line 7 (Sky Blue) will connect two of the municipal districts of the metropolitan region: Osasco and Sao Paulo. The line will be 24 kilometers in length, have 15 stations, and have a demand of 450 thousand passengers per day. The line will intersect the Yellow and Lilac lines.

Figure 36: Metro Characteristics Overview

Lines	Line 1 Blue	Line 2 Green	Line 3 Red	Network
Start of Commercial Operation	1974	1991	1979	-
Present length of lines (km)	20.2	7	22	49.2
Stations	23	8	18	46
Transfer Stations	3	2	1	3
Stations connecting with the railway	1	1	4	6
Stations with urban bus terminals	7	1	10	18
Stations with inter-city bus terminals	2	0	1	3
Station with car parking facilities	2	0	5	7
Number of cars of the fleet	306	66*	348	654
Number of cars used at peak hours	270	66	252	588
Minimum headway (s)	108	158	101	-
Maximum Speed (km/hr)	87	75	87	-
Commercial Speed (km/hr)	30	32	40	-
Passenger entry (million/year)	214	46	244	503
Passenger entry/km of line (million)	16.1	11.4	14.1	10.2

*Line 2 operates with 66 cars of Line 3 fleet

[Source: Metro-SP]⁹¹

3.3.4 Ridership Statistics

The Sao Paulo Metro has the second highest ridership per route kilometer in the world, second only to Hong Kong. In the year 2001, the Metro provided 714 million rides. This ridership is off its peak ridership of 721 million, which occurred in 1997.⁹² On an average weekday, the Metro provides rides for 1.7 million passengers.⁹³ The base fare for the Metro is R\$1.60 for a one-way trip, and a round trip ticket is discounted to R\$2.70. The average design capacity of the trains is 1350 passengers, but this can reach 200 passengers per train under crush loading.

3.3.5 Benefits

Due to its size, the Metro is only able to provide service for a small percentage of the population. But given a population as large as the SPMR, providing service for this small percentage still has a positive effect. During a period in 1996, part of the Metro system

⁹¹ Sao Paulo Metro. www.metro.sp.gov.br

⁹² Sao Paulo, Brazil Metro. www.nycsubway.org/sa/br/saopaulo

⁹³ Sao Paulo, Brazil: Helicopters and Social Fragmentation in the Developing Urban World. www.makabusi.com/2002/08/13

had to stop operation. During this time it is estimated that sales were decreased by 85 percent in many areas, stores were closed, 29,000 people were unemployed, and there was an increase in traffic jams and accidents.

The Sao Paulo Metro considers social responsibility as a priority, and based on these beliefs they calculated a social balance sheet in the year 2000. The balance sheet is an attempt to present the benefits that are produced for the community in a quantified format. Figure 37 provides a summary of costs and benefits, while Figure 38 shows a detailed breakdown of how these values were obtained.

Figure 37: Statement of the Net Cost/Benefit Result, 2000

Values in R\$000s	1999	2000
Net Revenues	622,349	617,796
Total Costs	-940,956	-831,423
Accounting Loss	-318,607	-213,627
Social Benefits	3,116,245	3,011,698
Net Result	2,797,638	2,798,071

[Source: Metro-SP]⁹⁴

The greatest benefit comes from the reduction of traveling time; in 2000, Metro estimated that they saved 361 million hours of travel time. This time translates into a value of R\$1.4 billion. The second greatest benefit came from reduced emissions. It is estimated that emission were reduced by 16.6 million kg, which have a positive value of R\$756 million. The third greatest benefit came from reduced operating costs of buses and automobiles. The Metro approximates that they reduces bus and automobile kilometers traveled by 420 million in 2000. This has an economic value of R\$621 million

⁹⁴ Sao Paulo, Brazil: Helicopters and Social Fragmentation in the Developing Urban World.
www.makabusi.com/2002/08/13

Figure 38: Statement of Benefits Produced by Metro, 2000

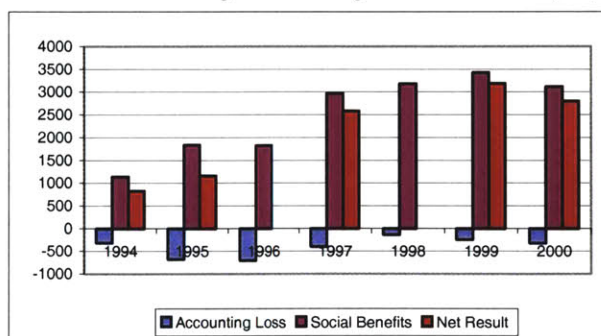
	Unit	1999		2000	
		Quantity	Value	Quantity	Value
		000s	R\$ 000s	000s	R\$ 000s
REDUCTION IN THE EMISSION OF POLLUTANTS	Kg/Year	16,829	724,077	16,571	755,594
REDUCTION IN FUEL CONSUMPTION	Liters/Year	432,110	203,041	416,789	264,265
REDUCTION IN THE OPERATING COSTS OF BUSES AND CARS	Km/Year	426,508	764,059	419,984	621,236
COST REDUCTION OF TRAVELLING TIME	HT*/Year	355,178	1,301,343	361,409	1,454,012
Travelling to workplace		226,000	572,533	229,965	639,301
Business		55,159	541,295	56,127	605,328
Others		74,019	187,515	75,317	209,383
REDUCTION IN THE NUMBER OF ACCIDENTS	Total Victims per Year	1.21	19,178	1.26	21,138
Hospital + Care Costs			6,917		7,624
Loss of Production			12,261		13,514
TOTAL			3,011,698		3,116,245

*HT = Hours of travel

[Source: Metro-SP]⁹⁵

The reduction of time traveled to work provides residents with more time for work, entertainment, sports and culture, and improves the quality of life. The reduction of emissions and vehicle kilometers traveled improves the air quality, reducing the occurrence of respiratory diseases.

Figure 39: Cost/Benefit Results for 1994-2000 (R\$000s)



[Source: SP-Metro]⁹⁶

⁹⁵ Sao Paulo, Brazil: Helicopters and Social Fragmentation in the Developing Urban World. www.makabusi.com/2002/08/13

⁹⁶ Ibid

3.3.6 Policies

Due to the small size of the Sao Paulo Metro network, it is not able to provide service for a large portion of the SPMR population. But even the small percentage of the population the Metro provides service for causes the trains to be overcrowded, especially at peak hours. Since the Metro is almost at capacity during peak hours there is no need for policy aimed at improving ridership; the attention of policy makers is focused on the problem of auto pollution.

In 1986, the National Environmental Council enacted a nation wide automotive emissions resolution called PROCONVE, which was established to extend the use of electronic injection and catalytic converters in order to reduce emissions. This resolution was followed up by legislation in 1992, which required catalytic converters in new cars and maximum carbon monoxide emissions of 12 grams/kilometer; still far behind northern countries. The most dramatic emission reduction policy enacted was Rodizio, based on the examples of Mexico City and Chile. This policy provided a reduction in the use of cars once a week according to registration plates. At first Rodizio was not mandatory, but based on the success of the trial period, it was fully implemented in 1996. During the trial period 95 percent of the residents obeyed the rules, and this resulted in a withdrawal of 456,000 cars per day. This translated into reduced carbon emissions by 330 tons per day, almost a 15 percent reduction.⁹⁷

3.3.7 Lessons Learned

While the Sao Paulo Metro has been successful at filling its trains, this is only due to the huge population and the small network. The Metro has been effective for the limited population it serves, but the network does not have the proper capacity, or integration to have a meaningful impact on the regional travel behavior. This ineffectiveness is further enforced by the lack of linkage between land-use and transit. The exclusive growth of

⁹⁷ Jacobi, Segura, & Kjellen, (1999). *Governmental responses to air pollution: summary of a study of the implementation of Rodizio in Sao Paul*. Environment and Urbanization, Vol. 11, No. 1, April 1999

the road network during the industrialization process created an auto-oriented environment, which has had detrimental environmental effects. The government has made some significant efforts to restrict vehicle usage, such as Rodizio. Yet while this has been successful at reducing emissions, there were no complementary measures taken to increase the size of the Metro and suburban rail networks. The government also supports a land code which allows the withdrawal of land from the market. This has resulted in retention of 27 percent of available construction land, which pushes up the price of land, and makes the city less dense. As a result, lower-income citizens have less capacity to purchase land and housing is restricted, and they are forced to distant, substandard and/or illegal accommodations.

3.4 Santafe de Bogotá: TransMilenio

Santafe de Bogotá is the capital of Colombia and the most populous city in the country. In the past 55 years the population of the city has increased by over 14 times, while the population of the country has only quadrupled. Within the last 22 year the population has grown from 3.8 to 7 million. The city covers an area of 311 square kilometers, and is composed of twenty local administrative units. The capital district covers an area of 1,587 square kilometers, yet 90 percent of the districts residents live within the city jurisdiction. Much of this population growth was due to massive urban migration resulting from regional and local guerilla violence, violence from drug trafficking in rural areas, and Colombia's transition from a rural to urban economy.⁹⁸ Bogotá is an important player in the Colombian economy, it accounts for 25 percent of the value added in manufacturing, and 35 percent of the domestic production services.⁹⁹

3.4.1 Context

The rapid population growth in Bogotá coupled with increasing commercial activity has led to a growing vehicle fleet that is straining the limited capacity of the road networks with severe congestion, and harming the citizens with increased air pollution. In 1980 the motorization rate was only 4 percent, with a vehicle fleet of 150,000.¹⁰⁰ By 1991, the number of registered vehicles in the city had grown to 342,902; 64.5 percent were cars, 14.2 percent were light-duty trucks, 10.7 percent were jeeps, 5.9 percent were public transport vehicles, and 4.7 percent were trucks. Post 1991, relaxed import restrictions led to significantly reduced vehicle prices, and a further increase in the demand for private automobiles. By 1996, there were approximately 559,000 vehicles registered in the city, of which 83.3 percent of these were private cars.¹⁰¹ Presently, there are over 832,000

⁹⁸ Onursal & Gautam, (1997). *Vehicle Air Pollution, Experiences from Seven Latin American Urban Centers*. World Bank Technical Paper NO. 373.

⁹⁹ Ibid

¹⁰⁰ Mozer & Thickett. *Sustainable Transport and Development Essay*.

¹⁰¹ Onursal & Gautam, (1997). *Vehicle Air Pollution, Experiences from Seven Latin American Urban Centers*. World Bank Technical Paper NO. 373.

private cars in the city, and this number is increasing by 70,000 in a normal year of economic growth.¹⁰²

The effects of the growing vehicle fleet are readily apparent. In 2000, only 14 percent of the city's residents owned a car, yet during peak traffic it can take more than an hour to travel five miles. Approximately 80 percent of the city's population uses public transportation; however, private vehicles occupy 95 percent of the road. The congestion in Bogotá has contributed to making it the fifth most polluted city in Latin America; automobiles contribute 70 percent of all air pollution: 700 tons of carbonic gas, 57 tons of hydrocarbons, 24 tons of nitrogen oxide and two tons of sulfuric monoxide every day.¹⁰³ The air pollution in Bogotá is considerably more harmful given that it is located 2600 meters above sea level where there is 27 percent less available oxygen than at sea level.

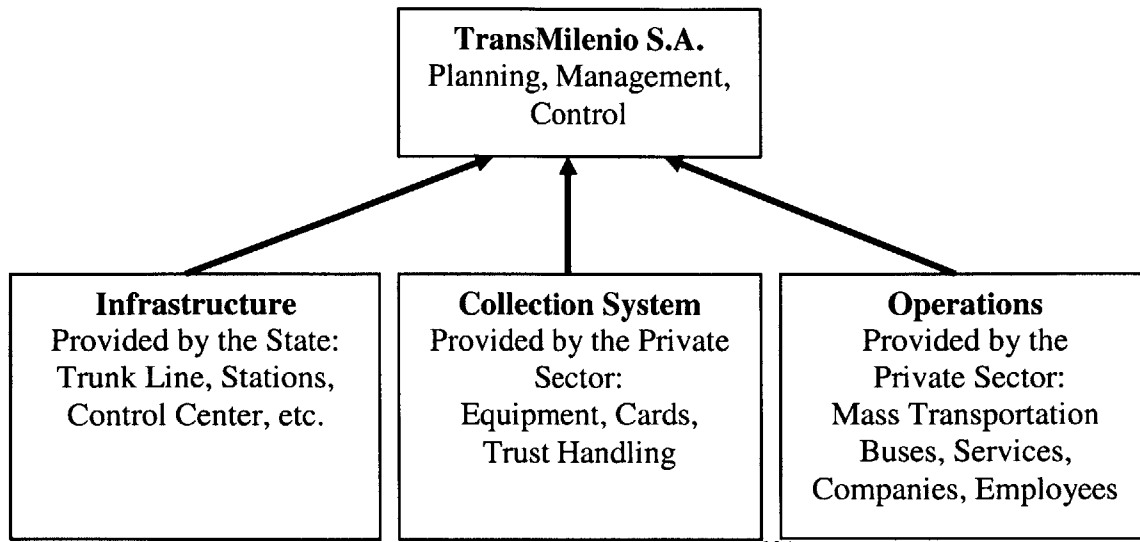
3.4.2 Institutional Framework

The Bus Rapid Transit system in Bogotá is a public/private partnership; public institutions provide infrastructure, planning, and control, while operations and billeting are contracted out to private companies. TransMilenio S.A. was created to plan the layout of the system, and manage the day-to-day operations through the control center.

¹⁰² Diaz, (2001). *Car Free Bogotá: the response to the transportation challenge*.

¹⁰³ The Bogotá Project, (2000). www.ecoplan.org/votebogota2000/

Figure 40: TransMilenio Organizational Structure



[Source: TransMilenio S.A.]¹⁰⁴

TransMilenio operators are a group of traditional local transport companies that are allied with national and international investors that own the buses and hire drivers and maintenance personnel. The concessions were awarded through an open bidding processes and the payment is related to the route kilometers that are served by each operator. The concessions set forth strict operating conditions for the private operators. The billeting system is privately operated, and includes the production and distribution of smart cards, acquisition and installation of turnstiles, validating systems, passenger information, and money handling. The operations of the BRT system is not subsidized by the government, it was designed for 100 percent farebox recovery.

3.4.3 System Overview¹⁰⁵

The BRT system in Bogotá is known as the TransMilenio. This system was built over a three year time period and was opened for operations in December of 2000. The systems infrastructure is composed of exclusive bus lanes based on the Curitiba model. Today the system is composed of 38 kilometers of exclusive busways, 57 stations, 4 terminals (transfer stations), 4 depots, 1 control center and 28 pedestrian crossings. The system

¹⁰⁴ TransMilenio S.A. www.transmilenio.gov.co

¹⁰⁵ TransMilenio S.A. www.transmilenio.gov.co:8080/transmilenio/Transmilenio.htm

operates with 470 articulated buses, each with a capacity of 160 passengers; and, 300 standard feeder buses, each with a capacity of 80 passengers. The buses are monitored by a control center that allows service and passenger access supervision. Each articulated bus is equipped with a Global Positioning Satellite system and a processing unit that reports its location every six seconds. The control center also receives information from the turnstiles that report the number of passengers entering and leaving the system. Supply and service demands are then coordinated, and contingencies managed in real time.

The systems stations are raised platforms that are designed to expedite loading and unloading; buses usually stop for no longer than 25 seconds at any given station. The stations vary in length from 62 meters to 198 meters, and can handle between one and three buses at the same time. The maximum speed of the articulated buses is 60 kilometers per hour, yet the average commercial speed is 27 kilometers per hour. The system has both express and standard lines. The express lines make less frequent stops, and the standard lines stop at each station. Due to the efficiency of this combination of services, the system can handle 45,000 passengers per hour per direction. TransMilenio S.A. has a 15-year plan to expand the BRT system to 22 corridors with a total length of 388 kilometers.

Figure 41: TransMilenio System Map, 2002



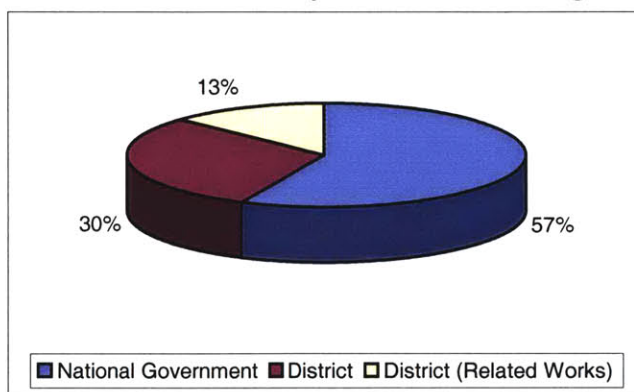
[Source: TransMilenio S.A.]¹⁰⁶

¹⁰⁶ TransMilenio S.A. www.transmilenio.gov.co

3.4.4 Infrastructure Spending¹⁰⁷

The total infrastructure costs for the TransMilenio BRT was US\$ 198.8 million, or approximately US\$5.3 million per kilometer. This total cost accounts for the trunk line, stations, terminals, depots, pedestrian walkways, the control center, and miscellaneous expenses. The majority of the infrastructure was funded by the national government, and the district funded the remainder. The cost of the trunk line was US\$94.7 million, which is about US\$2.5 million per kilometer. The total cost for 57 station was US\$29.2 million; US\$0.5 million per station. The total cost for the terminals (transfer stations) was US\$15.0 million, or US\$3.7 million per terminal.

Figure 42: TransMilenio Infrastructure Funding Sources



[Source: Cheatham]¹⁰⁸

The total cost for the depots was US\$15.2 million, or US\$3.8 million per depot. The total cost for pedestrian crossways was US\$16.1 million, or US\$0.6 million each. The cost of the Control Center was US\$4.3 million. Each articulated bus cost approximately US\$200,000; the total cost for all articulated buses was US\$94 million. When the total infrastructure costs are combined with the costs of the buses, the total system cost is approximately US\$8 million per kilometer. The total expected cost for the expanded system of 2016 is US\$1.97 billion.

¹⁰⁷ Subgerencia General, (2001). El Sistema de Transporte Masivo de Bogotá. *Primer Seminario Internacional de Transporte Urbano TransMilenio: La Experiencia de Bogotá*

¹⁰⁸ Cheatham, (2001). *Sustainable Urban Transportation in Developing Mega-Cities: A review of Policies, Regulations, and Technologies*. Massachusetts Institute of Technology, Masters Thesis.

Figure 43: TransMilenio Infrastructure Costs (US\$ millions)

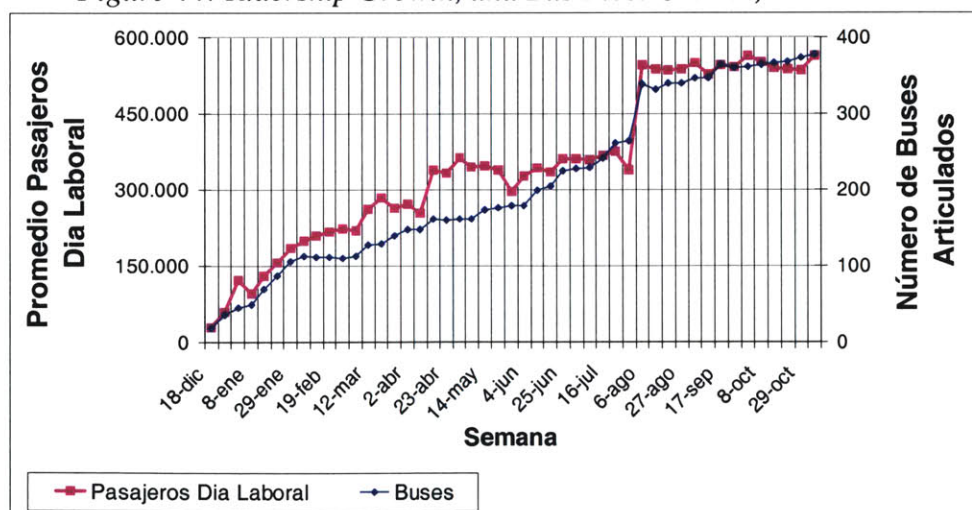
Component	Total Cost	Cost/Kilometer
Trunk Line	94.7	2.5
Terminals	29.2	0.8
Depots	14.9	0.4
Pedestrian Walkways	16.1	0.4
Depots	15.2	0.4
Control Center	4.3	0.1
Others	25.7	0.7
Total	198.8	5.3

[Source: TransMilenio]¹⁰⁹

3.4.5 Ridership Statistics

The TransMilenio is the second largest BRT system in the world, second only to Curitiba, Brazil, which has a daily ridership of over 1.3 million passengers. On its first day of operation the BRT carried 18,000 passengers, and today it now carries 750,000 passengers on an average weekday. Figure 44 shows the growth of average weekday ridership in contrast to the growth of the articulated bus fleet for the first year of operation.

Figure 44: Ridership Growth, and Bus Fleet Growth, 2000-2001

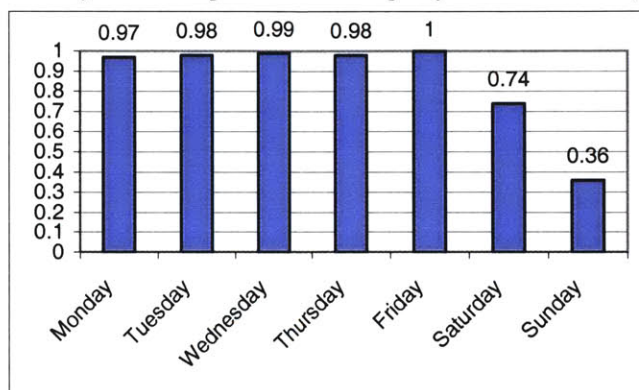


[Source: TransMilenio]¹¹⁰

¹⁰⁹ Cheatham, (2001). *Sustainable Urban Transportation in Developing Mega-Cities: A review of Policies, Regulations, and Technologies*. Massachusetts Institute of Technology, Masters Thesis.

During peak hours the buses are running at 75 percent of capacity, and during off peak hours when the number of buses operating is reduced the buses are running at 80 percent of capacity. During weekdays the ridership is very consistent, yet during the weekends the ridership declines. Figure 45 shows the daily ridership as a percentage of the peak ridership, which occurs on Fridays.

Figure 45: Daily Ridership as Percentage of Peak Weekday Ridership



[Source: TransMilenio]¹¹¹

3.4.6 Benefits

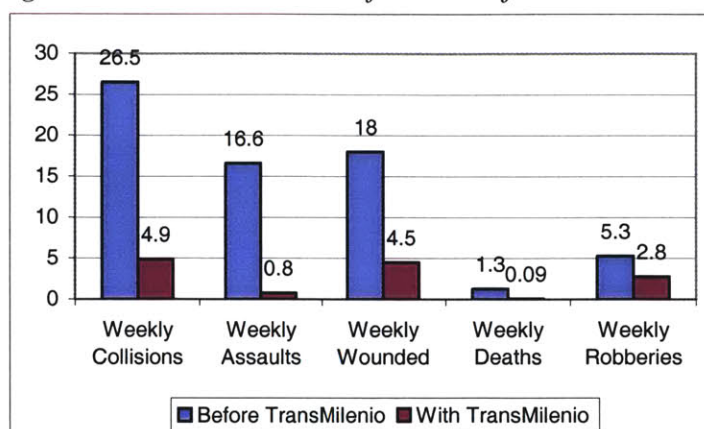
The benefits from the TransMilenio have been numerous. In the first five months of operation there was a 93 percent reduction in fatalities from traffic accidents; a 40 percent drop in select air pollutants; and a 32 percent reduction in travel time for TransMilenio riders.¹¹² From 2000 to 2001, weekly collisions have declined from 26.5 to 4.9, and weekly deaths have declined from 1.3 to 0.9.

¹¹⁰ Subgerencia General, (2001). El Sistema de Transporte Masivo de Bogotá. *Primer Seminario Internacional de Transporte Urbano TransMilenio: La Experiencia de Bogotá*

¹¹¹ Ibid

¹¹² Wynne, (2001). Bogotá's BRT Achieves Farebox Coverage of Operating Costs. www.apta.com/intnatl/intfocus/bogota.htm.

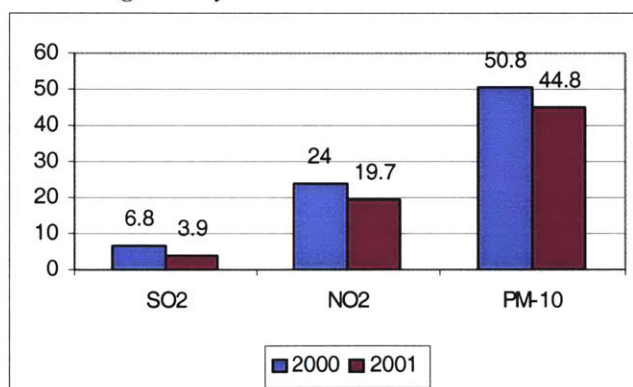
Figure 46: Accident Rates Before and After TransMilenio



[Source: TransMilenio]¹¹³

The TransMilenio has also had a positive effect on the air quality. From 2000 to 2001, daily SO₂ levels have decreased from 6.8 to 3.9 parts per billion (ppb), NO₂ levels have decreased from 24 to 19.7 ppb, and PM-10 levels have decreased from 50.8 to 44.8.

Figure 47: Average Daily Pollution Levels in 2000 and 2001 (ppb)



[Source: TransMilenio]¹¹⁴

TransMilenio S.A. performed a socioeconomic cost/benefit analysis of the BRT system that resulted with an Internal Rate of Return (IRR) of 61.4 percent. The most significant benefit for the public was the reduction of travel time; on average TransMilenio reduced travel time by 32 percent. When calculated with a hurdle rate of 12 percent, these time savings had a monetary value of US\$1.2 billion. The overall benefit to the public was

¹¹³ Wynne, (2001). Bogotá's BRT Achieves Farebox Coverage of Operating Costs. www.apta.com/intnatl/intfocus/bogota.htm.

¹¹⁴ Ibid

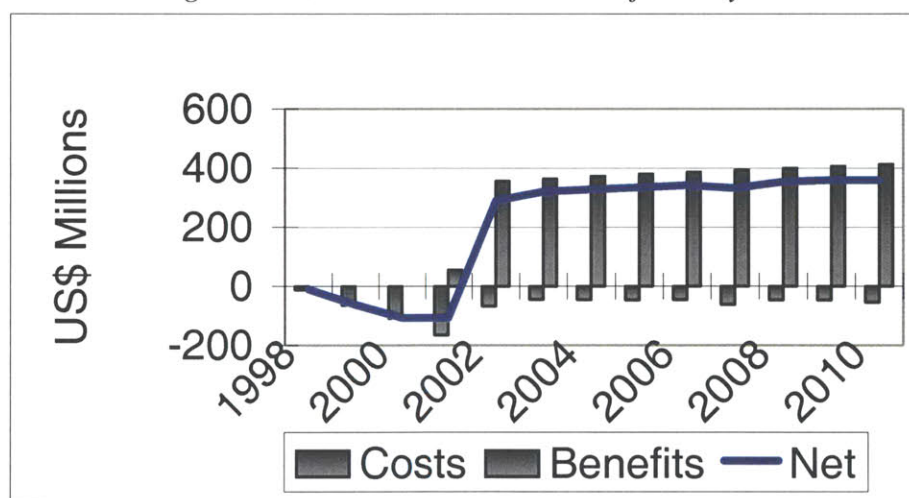
US\$1.0 billion. The analysis is presented in tabular and graphic form in Figure 48, and Figure 49.

Figure 48: Socioeconomic Cost/Benefit Analysis

US\$ Millions	NPV (12%)	Contribution
Total Costs	469.00	100.0%
Public Costs	218.51	46.6%
Pre-investment	5.41	1.2%
Infrastructure	164.12	35.0%
Maintenance	11.74	2.5%
Operation TMSA	18.95	4.0%
Direct investment TMSA	18.29	3.9%
Private Costs	250.49	53.4%
Vehicles	80.24	17.1%
Bus Operation	129.87	27.7%
Fare Collection System	14.29	3.0%
Fare Collection Operations	19.69	4.2%
Equipment Depots	6.39	1.4%
Benefits	1483.06	100.0%
Time of Travel	1202.90	81.1%
Public Transportation Operation	276.93	18.7%
Accidents	3.22	0.2%
Total	1014.06	

[Source: TransMilenio]¹¹⁵

Figure 49: Socioeconomic Cost/Benefit Analysis



[Source: TransMilenio]¹¹⁶

¹¹⁵ Subgerencia General, (2001). El Sistema de Transporte Masivo de Bogotá. *Primer Seminario Internacional de Transporte Urbano TransMilenio: La Experiencia de Bogotá*

¹¹⁶ Ibid

3.4.7 Policies

Bogotá has been very successful at putting together a combination of policies that support transit ridership and pedestrian oriented activities, and discourage automobile usage. One major initiative was to promote the use of bicycles; the recently completed bike network is the largest in the world. Through promotional campaigns and the completion of a 300-kilometer bike network the percentage of the population who use bikes for transportation has increased from 0.5 percent in 1997, to more than 5 percent in 2001. This percentage is expected to increase to 30 percent by the year 2005.¹¹⁷ The bike paths are strategically located so they can be used as a viable alternative transportation mode. Another measure taken to promote the bicycle was “Ciclovía”: on Sundays and holidays more than 120 kilometers of the city’s arteries are closed to automobiles for seven hours (7am –2 pm) leaving the roads open for bicyclists, skaters, and pedestrians. Ciclovía has been very successful with approximately 2 million people enjoying the social and environmental benefits associated with this day.¹¹⁸

There have been several policies aimed at reducing the use of the automobile in the city. The most aggressive is “Pico y Placa.” This policy restricts 40 percent of private vehicles from traveling during peak hours (7 to 9 am, and 5:30 to 7:30 pm) in the entire urban area, Monday through Friday. The restriction is based on the last digit of the license plate. The objectives of Pico y Placa are to raise the awareness of benefits associated with vehicle reduction, and to reduce the dependence on the automobile. Another measure taken was Car-Free Day, on February 24, 2000. On this day all private vehicles operation was restricted for 13 hours, and 6.5 million people were transported by public transit, bicycles, roller blades, taxis, and by foot. This removed 832,000 vehicles from the roads, and caused a 9 percent reduction in nitrogen oxides, a 28 percent reduction in carbon monoxide, and a 10 percent reduction in noise pollution.¹¹⁹ This was the first day in three years where no fatal traffic accidents were reported. The public support for Car-

¹¹⁷ The Bogota Project, (2000). www.ecoplan.org/votebogota2000/

¹¹⁸ ITDP, (2001). *Bike Use in Bogotá Jumps 900%, Boosts Local Bike Retailers*. Press Release.

¹¹⁹ The Bogotá Project, (2000). www.ecoplan.org/votebogota2000/

Free Day was so great that it was voted to hold Car-Free Day on the first Thursday of February each year. It was also voted that by the year 2015, Bogotá would be completely car free, making it the first car free city in the world.

Bogotá has also imposed fees and taxes that reduce the demand for the private automobile. Public parking fees were doubled within the city, and regulations on the fee for private parking lots were removed. A gasoline tax was imposed that increases the price by 20 percent over the previous year. The revenues from the parking and gasoline taxes are utilized to for road infrastructure and maintenance.

There has also been a considerable movement to increase the amount of public spaces as well as improving the existing spaces. The city administration has recently established more than 1,100 new parks and has reclaimed more than 1,400. In addition, “El Porvenir,” a 17-kilometer long, 15-meter wide, shaded walkway is under construction, and is the longest in the world.¹²⁰

3.4.8 *Lessons Learned*

Bogotá has been highly successful and innovative in their attempts to curb the growth of the vehicle fleet. The use of both vehicle pricing policies and vehicle restriction policies has decreased the total Vehicle Miles Traveled and reduced the dependence on the automobile. These policies in combination with public promotions of bicycle and transit use have gained the public support and changed the face of the city. Bogotá has clearly demonstrated the benefit and need to attack the problem from several angles, and gain the support of the public.

TransMilenio has proven to be an effective mode of transportation and ridership has steadily increased. The percentage of the population that uses TransMilenio is low, but this is due to the limited size and scope of the network. TransMilenio is in its infant stages, and the modal split will shift as the network grows to cover more of the city. The long-term growth plan covers the entire city, and is planned to be implemented within the

¹²⁰ The Bogotá Project, (2000). www.ecoplan.org/votebogota2000/

next 15 years. Bogotá's choice of BRT over heavy rail has led to expedited construction process and a price that is an order of magnitude less. Due to the success of the Bogotá model, it is being studied by other Latin American capital cities such as Lima, Quito, Santiago de Chile, Panama City and Guatemala City.

4 Guangzhou: Case Study

Due to the economic reforms and opening of China, the city of Guangzhou has been transformed into an economic hotbed. Since the early 1990's Guangzhou has seen double-digit economic growth and a surge of foreign direct investment. This influx of capital has led Guangzhou to have the highest level of disposable income per capita of China's 10 largest cities.¹²¹ As the level of income increases, so does the use of private motor vehicles. The city of Guangzhou is struggling with one of the fastest growing motor vehicle fleets in the world. This rapid motorization, along with a mass migration of workers from the countryside has had detrimental effects on the environment of Guangzhou.

4.1 Demographic Overview

Guangzhou, often referred to as China's commercial "Powerhouse," is the economic center, and political capital of the Guangdong Province. The city is also known as the entrepreneurial hub of China, as well as a major transportation, and communications hub. Guangzhou has an ideal position; located at the center of the Pearl River Delta, it sits in the apex of a highly productive economic region including Hong Kong, Shenzhen, and Macau.¹²² The Municipality of Guangzhou consists of ten districts and two county level cities, and covers an area of 7,434 square kilometers. The registered population is approximately 10 million, and on an average day around 1.8 million people commute into the city.¹²³ The population is rapidly expanding, and is projected to reach 13.8 million by the year 2010.¹²⁴

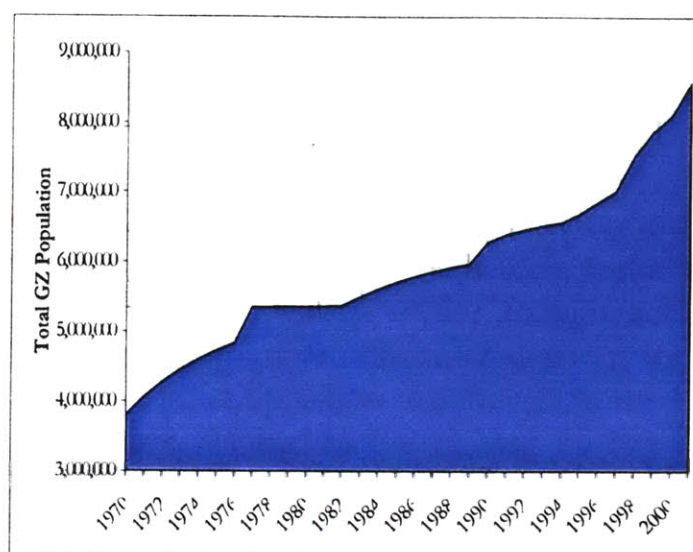
¹²¹ Ling 2000

¹²² Guangzhou Economic Brief; www.britishembassy.org

¹²³ Ibid

¹²⁴ Cheatham, Benjamin (2002) *Sustainable Urban Transportation in Developing Mega-Cities: A Review of Policies, Regulations and Technologies*. Massachusetts Institute of Technology.

Figure 50: Guangzhou Population



[Source: Lahmeyer]¹²⁵

While Guangzhou has recently achieved a low birthrate, the major population increase is caused by an influx of people who come from outside of Guangdong to seek work and business. In 1998 approximately 1.75 million people immigrated to Guangzhou, of which over 60% come from other provinces.¹²⁶ With the implementation of city planning, the residents of the old city center are slowly moving outwards to rural areas. This de-densification of the downtown is leading to increased dependence on the transportation infrastructure, and urban sprawl.

4.2 Economic Indicators

Guangzhou's role as the southern gateway to China has been greatly consolidated due to the economic reforms of 1978, and the export-driven economic development of the Pearl River Delta Region.¹²⁷ Due to this consolidation the economy of Guangzhou has seen rapid growth in the last twenty years. On average this growth has been between 12 to 13 percent per year. In 2001 the GDP grew 12.7% to 268.5 billion yuan RMB. While the

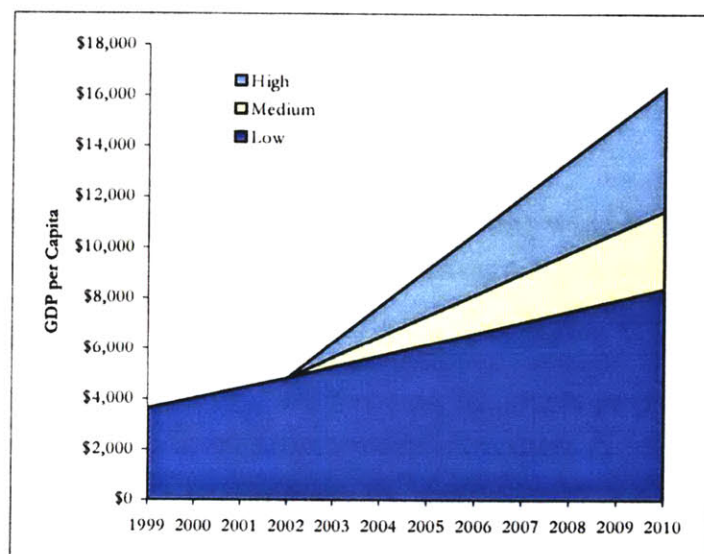
¹²⁵ Lahmeyer, Jan. (2001) "Poulstat" Website. University of Utrecht.
www.library.uu.nl/wesp/populstat/populhome

¹²⁶ GRIEP & Center for Environment Peking University. (2001). *Capacity Development for NOx Pollution Control in Guangzhou*

¹²⁷ World Bank, (1998). *Guangzhou City Center Transport Project*

growth rate was less than the previous year, it was still higher than both Shanghai and Beijing.¹²⁸ The per capita GDP of Guangzhou was approximately 38,000 yuan RMB (US \$4,586). Three scenarios for GDP per capita growth are shown in Figure XX.

Figure 51: Guangzhou GPD Per Capita Growth Scenarios



[Source: Vennemo et al]¹²⁹

Exports in 2000 were up 19.8% to US\$ 11.818 billion, and foreign direct investment was slightly higher at US\$2.989 billion. Urban per capita disposable income was up 16.2%, to 13,967 yuan RMB, and rural per capita net income reached 6,086 yuan RMB.

4.3 Rapid Motorization

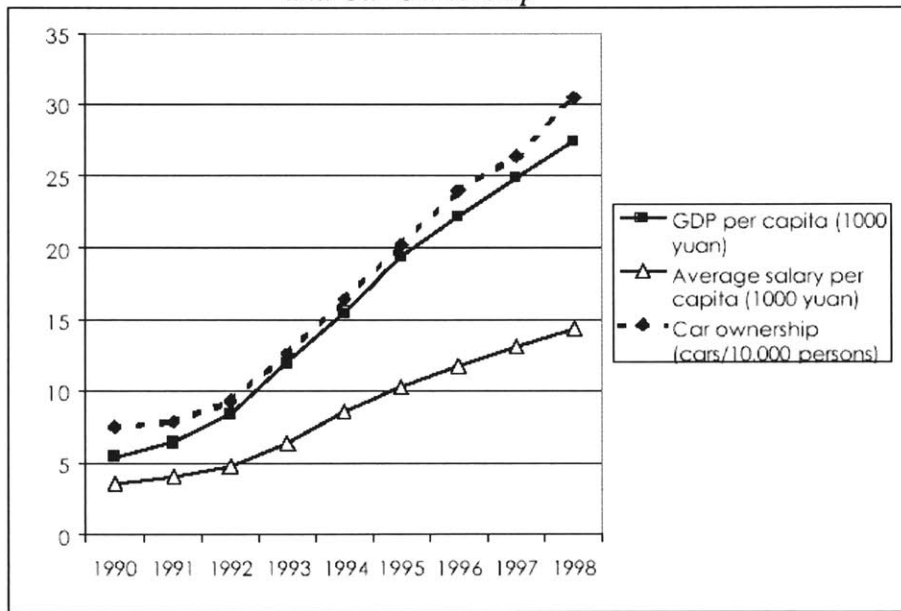
Pre 1990, a very small percentage of passenger trips were handled by private motor vehicles, the majority of trips were by bus and bicycle. While these conditions were favorable for the environment, the average citizen was forced either to ride slow crowded buses, or ride long distances by bicycles. Air pollution in Guangzhou was problematic, yet the majority of this pollution was from sources other than the vehicles. The most

¹²⁸ Guangzhou Economic Brief; www.britishembassy.org

¹²⁹ Vennemo, Trong & Changzhong, (1999). *General Development Scenarios During 1995-2010 in Guangzhou*. ECON/NILU. Norway

significant pollution sources were industrial, electric power, and household cooking and heating. Yet, post 1990 the economy of Guangzhou, similar to the rest of southern China, began to experience rapid growth. The GDP was growing at 24.5% annually.¹³⁰ This economic growth spurred an inflow of workers from the countryside and caused a drastic population increase. The increased population coupled with the new high levels of disposable income per capita set the stage for rapid growth of the private motor vehicle fleet.

Figure 52: Guangzhou GDP per Capita, Average Salary per Capita, and Car Ownership



[Source: Ernst & Hook 2001]¹³¹

Between the years of 1991 to 1995 vehicle ownership has increased at an average annual rate of 21.3 percent, within which motorcycles ownership was growing at an average 30 percent annual rate.¹³² As shown in Figure 53, from 1980 to 1998 the total motor vehicle population of the Guangzhou urban area has increased by a multiple of over 20. In 1997 the Municipal Government placed a restriction on motorcycle licenses. The strict

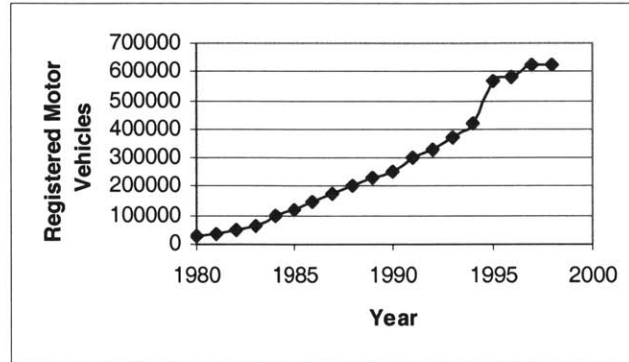
¹³⁰ Ernst & Hook, (2001). *Making World Bank Transportation Lending Sustainable: Lessons from the Guangzhou City Center Transport Project*

¹³¹ Ibid

¹³² World Bank, (1998). *Guangzhou City Center Transport Project*

enforcement of this new law quickly stopped the 50 percent annual increase of the motorcycle population that was occurring between the years of 1991 to 1995.

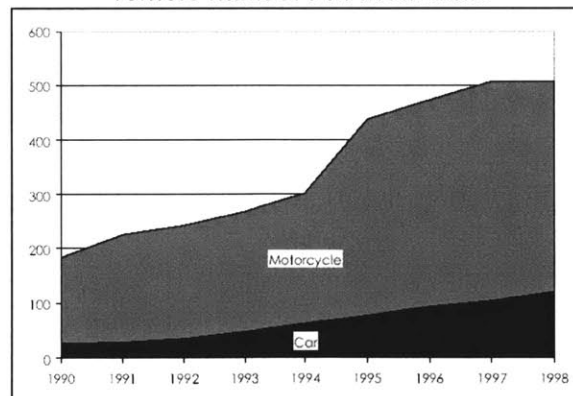
Figure 53: Historical Growth of Motor Vehicles in Guangzhou



[Source: GRIEP & GUTS]¹³³

Figure 54 compares the growth of the motorcycle fleet to the private car fleet, and the effects of the motorcycle licensing restriction of 1997 can clearly be seen. In 1992, motor vehicles accounted for only 16 percent of the modal split, compared to 1998, where they account for 28 percent. In this same time period bicycle trips have seen a major reduction, from 34 percent to 20 percent, and transit trips have only seen minimal growth, 20 percent to 24 percent of trips. Figure 55 displays the modal splits for 1992 and 1998.

Figure 54: Private Car and Motorcycle Ownership in Guangzhou, vehicle numbers in thousands

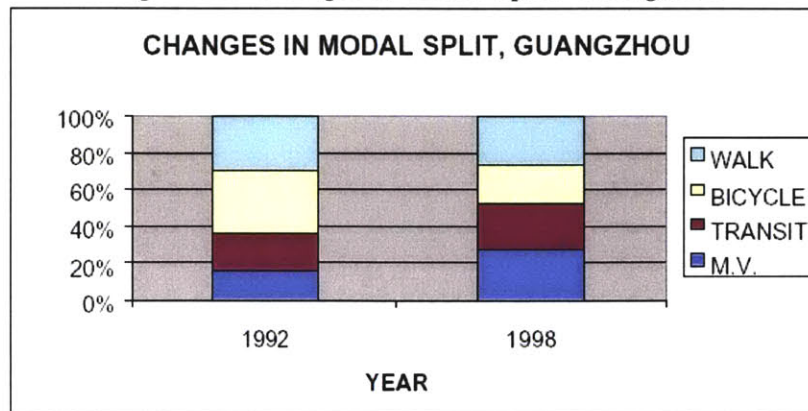


[Source: GTPRI 2000]¹³⁴

¹³³ GRIEP & Center for Environment Peking University. (2001). *Capacity Development for NOx Pollution Control in Guangzhou & GUTS*, (1995). Environment and Urban Development Operations Division, China and Mongolia Department, The World Bank

¹³⁴ GTPRI, (2000). *Guangzhou Traffic Demand Management Study: Final Report*

Figure 55: Changes in Modal Split, Guangzhou



[Source: Ernst & Hook 2001]¹³⁵

The result of the rapid motorization is a significant increase in the pollution caused by automobiles. In 1988, mobile sources accounted for 64 percent of NO_x emissions in Guangzhou, while in 1994, this number has increased to 79 percent. In this same time period the emissions of CO have risen from 63 percent to 89 percent.¹³⁶ Figure 56 shows the distribution of pollution sources for Guangzhou in 1995.

Figure 56: 1995 Distribution of Pollution Sources in Guangzhou

Urban Area	SO ₂ (%)	NO _x (%)	CO (%)	particulates (%)
Industrial Source	84.9	56.6	3.5	92.6
Traffic Source	3.2	38.9	94.8	1.7
Civil Source	4.1	1.8	1.5	0.6
Tertiary Source	7.8	2.7	0.2	5.1
Total	100	100	100	100

[Source: GRIEP 2001]¹³⁷

The rate of motor vehicle growth has also had a considerable effect on the level of congestion within the city center. Many segments of the road network experience severe congestion throughout the workday, and gridlock at peak hours. The average road speed

¹³⁵ Ernst & Hook, (2001). *Making World Bank Transportation Lending Sustainable: Lessons from the Guangzhou City Center Transport Project*

¹³⁶ World Bank, (1998). *Guangzhou City Center Transport Project*

¹³⁷ GRIEP & Center for Environment Peking University. (2001). *Capacity Development for NO_x Pollution Control in Guangzhou*

in the old city center was 13 kilometers per hour or less in 1998, and the peak hour volume-capacity ratios on most of the arterial roads was over 0.8, and over 1.0 in a few cases.¹³⁸

4.4 Public Transportation

Guangzhou has one of the best public transportation systems in China. This is primarily due to the introduction of joint-venture bus companies in 1993. Market forces have led to significant improvements in transit services and a reversal of ridership decline. In 1998 there were 6 companies operating buses, of which five had partners in Hong Kong and Macao. Guangzhou's public transit companies carried 33 percent more passengers in 1996 than in 1993 (869 million passenger trips total).¹³⁹

4.4.1 Rail

Nationally, Guangzhou is a major node in the railway network. Locally the city is investing greatly in a heavy rail metro system. The first line of the metro system was completed in 1999, and line 2 and 3 are under construction. The ridership statistics have been much lower than expected due to high fares and inconvenient routes.

4.4.2 Bus

Guangzhou's bus services are provided primarily through six major municipal bus companies. Within the city there is a dense network of short urban services that are offered at low fares, while increasingly there is a number of new urban/suburban routes that are charging higher fares. In 1995, Guangzhou had a total of 4000 heavy and middle duty buses, of which 1000 were trolley buses. Approximately 60 percent of these buses ran on diesel, while the rest ran with gasoline.¹⁴⁰ Overall the buses do not meet modern

¹³⁸ World Bank, (1998). *Guangzhou City Center Transport Project*

¹³⁹ Ibid

¹⁴⁰ GRIEP & Center for Environment Peking University. (2001). *Capacity Development for NOx Pollution Control in Guangzhou*

standards for comfort and efficiency. The deficiency of the bus system is further exaggerated by the worsening congestion.

4.4.3 Minibus¹⁴¹

Approximately 1042 minibuses have licenses to operate within Guangzhou. The drivers are hired primarily on a shift basis, and are often assigned to a route. Yet, given that there is no legal framework to govern the routes they are often changed and some time ignored.

4.4.4 Ferry¹⁴²

The municipal government owns and operates 63 ferries. The primary use of the ferries is by cyclists and pedestrians to cross rivers, yet the number of passengers is declining as the number of bridges and tunnels increases. Growth is expected in the ferry business as the city expands and longer routes are created.

4.4.5 Taxi

In 1995, the Guangzhou taxi fleet was composed of about 14,500 taxis. This was approximately 2.5 percent of the total vehicle population. On an average day an individual taxi would operate for 16 hours, and drive a total of 300-350 kilometers.¹⁴³ As the average GDP per capita rises, the demand for taxis is increasing. This is adding considerably to the local congestion and pollution.

¹⁴¹ GUTS, (1995). Environment and Urban Development Operations Division, China and Mongolia Department, The World Bank

¹⁴² Ibid

¹⁴³ GRIEP & Center for Environment Peking University. (2001). *Capacity Development for NOx Pollution Control in Guangzhou*

4.5 Non-Motorized Transport

Despite the rapid motorization of Guangzhou, bicycling and walking still remain the most predominant form of transportation. Between 1984 and 1992 bicycle trips as a percentage of all person trips remained constant at 34 percent. Over this same time period the amount of walking trips declined from 39 percent to 30 percent, and motor vehicle trips increased from 27 percent to 36 percent.¹⁴⁴

Between the years of 1978 to 1995 the amount of bicycles in the city center increased from 0.9 million to 3.1 million. The Guangzhou bicycle fleet density is one of the highest in the world, at approximately 1.2 bicycles for every officially registered person.¹⁴⁵ The bicycle policies in Guangzhou have recently gone through two distinct stages. In the early 1970's up through the mid 1980's the bicycle was an increasingly popular mode of travel. As the per capita income rose in Guangzhou, so did bicycle ridership. Most new roads were built with segregated bicycle lanes, and almost all roads were open to bicyclists. In the late 1980's it was felt that the bicycle population had reached saturation and as the roads became increasingly more congested the conflicts between automobiles, motorcycles and bicycles worsened. Most city intersections were ill equipped to deal with large numbers of bicycles and motor vehicles. This led to restriction of bicycles on certain roads and increased danger on other high volume roads. Bicycle riders were further inconvenienced by the newly built overpasses that force the riders to dismount their bicycles and push them over. These deterrents to bicycle riding have cause the modal split of bicycle trips to fall from 34 percent in 1992 to 20 percent in 1998, and it is projected that this decline will continue to leave only a 10 percent by 2010.¹⁴⁶

As the road network became increasingly more congested, the municipal government added many features to segregate vehicles from pedestrians. This was an attempt to increase the speed on the roadways and provide a safer pedestrian environment. These

¹⁴⁴ World Bank, (1998). *Guangzhou City Center Transport Project*

¹⁴⁵ Ibid

¹⁴⁶ Ernst & Hook, (2001). *Making World Bank Transportation Lending Sustainable: Lessons from the Guangzhou City Center Transport Project*

added features, such as overpasses, physical barriers, and crosswalks are having a negative impact on pedestrians. The pedestrians are suffering severance, which means that have to walk out of their way and increased distances, as a result of the upgrading of the roads to primary arterial status and the onslaught of new infrastructure.¹⁴⁷

4.6 Guangzhou Metro¹⁴⁸

The Guangzhou Metro Corporation was established in December of 1992, as an independent government enterprise. With the status of independent enterprise it is expected that the Metro Corporation will produce revenue autonomously. The primary responsibility of the Metro Corporation is to design, construct, operate and maintain a rapid rail transportation system in the city of Guangzhou. The Metro Corporation also has developed a number of smaller businesses to diversify its portfolio and capture additional revenues that are generated from the metro. These subsidiaries fall into four core businesses: Real estate, advertising, commerce, and communications. Since the official opening of the first metro line in June of 1999, the Metro Corporation has not been profitable; it is only with the additional revenues from their subsidiaries that they are almost breaking even. The financial summary of the Metro Corporation is shown in Figure 57.

Figure 57: Guangzhou Metro Corporation Financial Summary for 2001 (US Dollars)

Item	Line 1 Operation	Subsidiaries	Total
Operating Revenues of Year 2001	22,465,060	38,189,157	60,654,217
Deduct: Operating Costs	26,368,675	30,463,855	56,832,530
Operation Profit of Year 2001	-3,903,614	7,725,301	3,821,687
Deduct: Other Adjustment Items	1,891,566	2,114,458	4,006,024
Operating Profit after Adjustments	-5,795,181	5,610,843	-184,337
Add: Compensation Income	4,819,277	-	-
Deduct: Fixed Assets Depreciation Of Line 1	6,224,096	-	-
Operating Profit After Recovering Loss and Depreciation	-7,200,000	5,610,843	-1,589,157

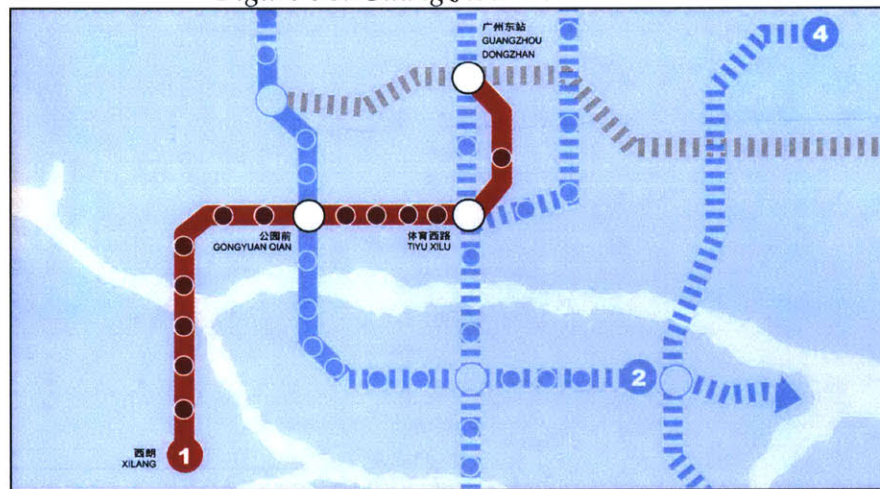
¹⁴⁷ Ibid

¹⁴⁸ Guangzhou Metro Annual Report, (2001). And interviews with Guangzhou Metro Staff

4.6.1 Line 1 Summary

Metro Line 1 was officially opened June 28, 1999, and provides service between Xilang and, Guangzhou Dongzhan. The line has 16 total stations along its length of 18.5 kilometers, 14 below ground, and two above ground. The station density is 1 for every 1.16 kilometers. Twenty-one trains operate 17 hours daily with an interval time of 6 minutes between trains during peak hours. Line 1 was built to accommodate a maximum of 1.1 million passengers per day.

Figure 58: Guangzhou Metro Line 1



4.6.2 Construction Costs

The construction of Metro Line 1 was the biggest construction project the city has ever undertaken. The entire investment was financed by the city and managed by the Guangzhou Metro Investment Coordination office, set up specifically for this project. The total investment in Line 1 was approximately US\$1.48 billion. Of this investment, 35 percent was spent on construction and installation, 35 percent was spent on equipment, 24 percent of the investment was to be amortized, 5 percent was spent on closing costs, and 1 percent was spent on miscellaneous items. The average construction cost per kilometer was approximately US\$80 million.

Figure 59: Total Construction Investment for Metro Line 1 (US Dollars)

Total Investment in Construction	1,477,301,205
Investment in Construction and Installation	516,228,916
Equipment Investment	521,168,675
Investment to be Amortized	360,614,458
Other Investment	5,819,277
Investment in Ending Projects	73,469,880
Average Construction Cost Per Kilometer	79,867,470

The construction of the project was initiated in 1993, and took 66 months to complete. During the course of the project over 4.3 million cubic meters of soil was excavated, 662 thousand square meters of land was requisitioned, and 179 thousand square meters of buildings were removed.

4.6.3 Operations

During its first year of operation Metro Line 1 carried over 64.4 million passengers, with an average daily ridership of 176,000 passengers. In the second year the ridership decreased slightly as the excitement wore off and the price became a barrier. The fare structure for Line 1 varies depending on the distance traveled; the minimum cost is 2 yuan RMB, and the maximum cost is 6 yuan RMB. The average distance traveled on Line 1 is 6.9 kilometers, and the average ticket price is 2.91 yuan. On average, the trains are running at 13.3 percent of capacity.

Figure 60: Major Operations Index, Line 1

	2001	2000
Daily Average Passenger Traffic	174,000	176,000
Years' Highest Daily Passenger Traffic	312,000	393,000
Average Running Distance (KM)	6.9	6.93
Average Ticket Price (RMB Yuan)	2.91	2.98
Average Full-load rate (%)	13.29	14.9

In 2001 the most popular station (Tiyuxi) was the starting point for 9 million passengers trips, and the least popular station (Xilang) was the starting point for 721,000 passenger trips. Figure 61 shows the total amount of passengers at each station for the year 2001.

Figure 61: Total Passengers Per Station, 2001 (Ten Thousands)

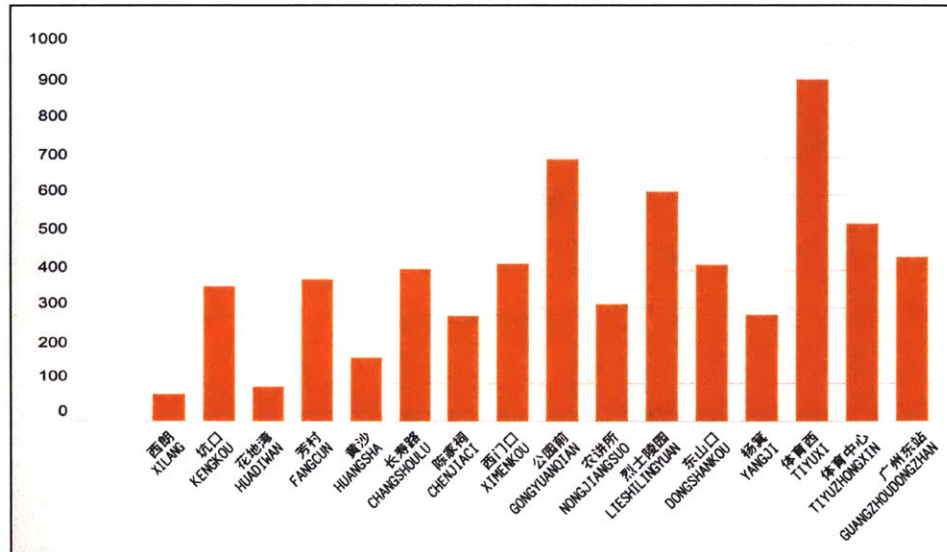
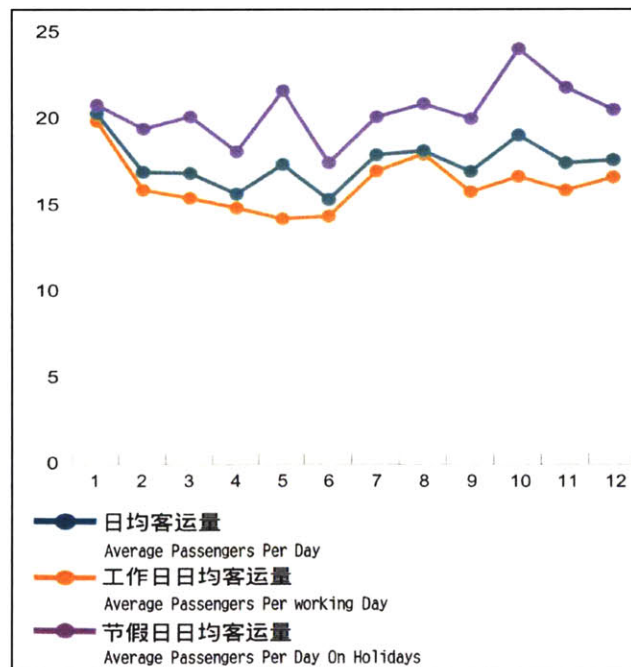


Figure 62 shows the average passengers per day in each month for 2001. As can be seen, the ridership on holidays exceeds that of the normal workday.

Figure 62: Average Passenger Volumes Per Day (Ten Thousands)



The operational costs of Line 1 were approximately US\$26.4 million in 2001. Of this total expense 34 percent was spent on power, 4 percent was spent on materials, 3 percent was spent on subcontracted maintenance, 10 percent was spent on taxes, 37 percent was spent on salaries and related expenses, and 12 percent was spent on miscellaneous items.

Figure 63 shows the breakdown of operational costs for years 2000 and 2001.

Figure 63: Operations Costs for Metro Line 1, US\$

	2001	2000
Transport Operation Expenditure	26,368,675	26,146,988
Power Expenses	8,948,193	8,961,446
Material Expenses	1,162,651	1,438,554
Subcontracted Maintenance Expenses	749,398	833,735
Tax	2,674,699	2,697,590
Salaries and Related Expenditure	9,639,759	9,228,916
Other Costs	3,193,976	2,986,747
Total Operational Length (Ten Thousand Train-Kilometers)	1,112	997
Carriage Kilometer Costs (Excluding the Depreciation)	23,711	26,217

4.6.4 Lines 2 and 3

Metro Line 2 is currently under construction, and expected to open a partial section in the end of 2002. This first section will be 9 kilometers in length, have 9 stations, and travel from Sanyuan Li, to Xiaogang. The rest of the line is scheduled to open in the end of 2003. The total length of Line 2 will be 23.3 kilometers, with 20 stations. The station density is 1 for every 1.17 kilometer. The line will travel from Pazhou, to Jiangxia, and intersects Line 1 at Gongyuan Qian. The total investment in Line 2 is expected to be US\$1.4 billion, of which 91 percent has already been committed.

Metro Line 3 is still in the planning process with only small amounts of construction underway. This line is planned to be 35.8 kilometers, with 18 stations. The station density is 1 for every 1.99 kilometers. Line 3 will intersect Line 1 in Tiyu Xi and Guangzhou Dong, and intersect Line 2 in Kecun. The Line will form a “Y,” with ends at

Tianhe Keyun Zhan, Guangzhou Dongzhan, and Panyu Guangchan. The major function of the Line will be to connect the growing district of Panyu with the Guangzhou city center. The Panyu district is a new planned development zone and is expected to soon have a population of 1.2 million in the center. The construction period for Line 3 is 54 months, and is scheduled to open in 2006. The total estimated construction investment is US\$ 1.83 billion.

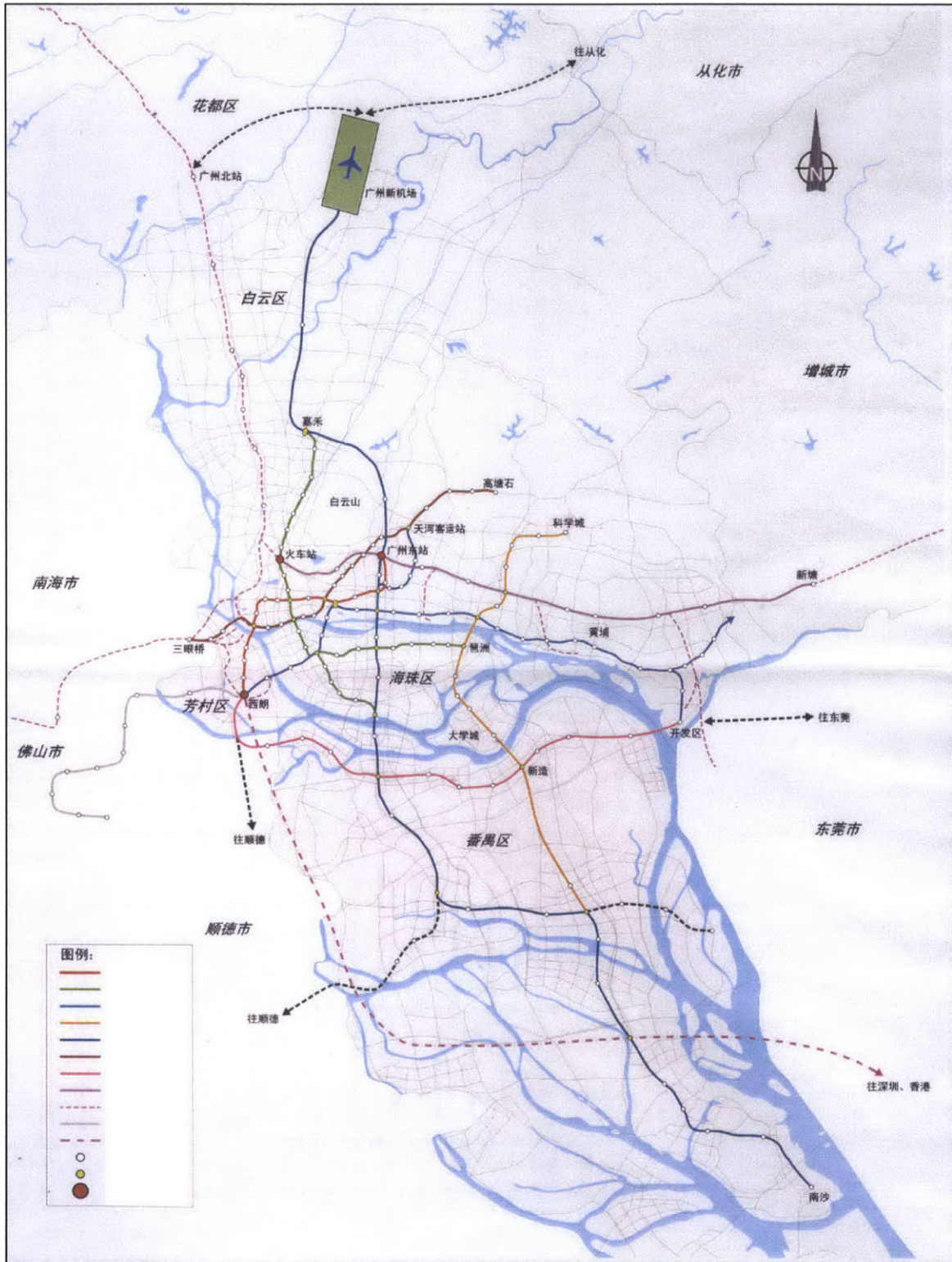
4.6.5 Long-Term Plans

The Guangzhou Metro Corporation has both a near and long-term plan for the future expansion of the rail network. The near-term plan is set to be finished in 2016, and will be composed of 4 lines with a total length of 129.4 kilometers. The near-term plan also includes an express train to the new international airport. The long-term plan is to build a total of 7 lines with a complete system length of approximately 290 kilometers.

图例:

- 地铁一号线
- 地铁二号线
- 地铁三号线
- 国铁
- 广州东站至新机场
- 三元里至嘉禾
- 西朗至开发区
- 科学城至大学城
- 西朗至佛山
- 国铁提升路段
- 一般车站
- 换乘站
- 枢纽站

Figure 65: Long-Term Plan



5 Mass Rapid Transit Options

The problems of inadequate and congested urban transportation are damaging to a cities economy and harm both the rich and the poor. A common solution to this problem is increasing the road infrastructure. Yet this option is inequitable, as this strategy will lead to a progressive decline of public transportation and will only generate more congestion. The sustainable solution is a long-term investment plan in Mass Rapid Transit (MRT). Yet the decision goes beyond this, as there are three distinct MRT options: Bus Rapid Transit (BRT), Light Rail Transit (LRT), and Heavy Rail Transit (HRT). Each option has benefits and drawbacks that need to be clearly understood before such an investment is made.

5.1 Bus Rapid Transit (BRT)

Bus Rapid Transit (BRT) is the cheapest form of Mass Rapid Transit (MRT). It has seen widespread use in Latin America for the past 20 years, yet is rare in the rest of the developing world. The reason for this is partly because buses are looked upon as a “bottom-of-the-market” technology, and often disregarded for more attractive options such as metro.¹⁴⁹ The capacity of the bus system is also seen as limited due to the size of the vehicles, and the integration with traffic. Some of this stigma is being overcome with the development of technologically advanced articulated buses, and the deployment of global positioning satellite tracking systems. These new technologies have increased both the efficiency and capacity. Other developments, which have improved the operations of BRT systems, are off-vehicle ticketing and elevated platforms. These features improve the speed of loading and unloading. BRT can take the form of dedicated, or shared center lanes along existing street routes within the city, or along the freeways. BRT is most effective when given segregated lanes, high capacity articulated buses, and elevated platforms. Busways are the most flexible form of MRT from implementation to operation.

¹⁴⁹ World Bank, (2002). *Cities on the Move, A World Bank Urban Transport Strategy Review*

5.2 Light Rail Transit (LRT)

“Light rail” does not signify the weight of the vehicle; rather, it refers to the operational characteristics and service provided. Light Rail Transit (LRT) systems operate conventionally in on-street tramways, as in Eastern Europe and Egypt, and on segregated and elevated systems, as is Kuala Lumpur and Singapore.¹⁵⁰ The popularity of LRT is growing in developed countries where it serves as a high quality alternative to the automobile. The capacity, efficiency, and cost of LRT make it most effective for low volume corridors, and offers questionable benefits for densely populated developing cities. When operating at-grade within the street network LRT offers little or no performance benefits over BRT. The flexibility of the LRT system is very limited, and financially it is a very risky investment. The most significant advantage of LRT is the environmental benefit of reduced air pollution, compared to the bus and automobile. The fixed tracks of a LRT system also signal a long-term commitment to public transit. For the most part, LRT systems have been beneficial to the middle and upper class.

5.3 Heavy Rail Transit (HRT)

Heavy rail transit (HRT) systems, commonly referred to as metros, are characterized by their ability to move large quantities of people at high rates of speed. They have a widespread use that is somewhat skewed to Europe and North America. They are commonly the most expensive form of MRT, but they have the highest capacity and speed. They operate free from congestion in subways or on elevated guideways. The permanence of HRT networks can provide a structure for urban growth and a catalyst for development. HRT systems have the most significant impact on the regional economy by improving efficiency and mobility, reducing travel times, and creating agglomeration economies. The metro systems themselves are rarely profitable and often highly subsidized by government, yet the increase in density along HRT corridors reduces urban sprawl and decreases the total need for infrastructure spending. The fares for HRT are often more expensive than BRT, but the service is more efficient and more accessible.

¹⁵⁰ World Bank, (2002). *Cities on the Move, A World Bank Urban Transport Strategy Review*

5.4 Comparison

5.4.1 Capacity/Speed

The capacity and speed of MRT systems is critical to their overall efficiency and economic benefit. BRT and LRT systems have similar performance characteristics, while HRT systems far exceed them in both capacity and speed. The most efficient BRT systems usually operate with articulated buses that have a capacity of up to 160 passengers. The average speed for BRT systems is 17 to 20 kilometers per hour, but maximum speeds of 60 kilometers per hour are sometimes achieved. In Curitiba, Brazil, the BRT system has reached peak capacities of up to 20,000 passengers per hour per direction. They achieved this capacity using 23-meter double-articulated buses with 5 doors each. LRT systems have similar operational capacities and speeds as BRT systems. They often utilize medium capacity cars with maximum capacities of approximately 116 passengers. They run with two to four trains operating in tandem, and have an average speed of 20 kilometers per hour, and a maximum speed of 70 kilometers per hour. HRT systems typically operate with a maximum of ten cars per train. Each car can handle about 150 passengers: 75 sitting and 75 standing. In Hong Kong, trains operating with headways of 2 minutes have been carried up to 80,000 passengers per hour per direction. More commonly HRT systems run with 60,000 passengers per hour per direction.

Figure 66: MRT Capacity and Speed Comparison

	Heavy Rail Transit	Light Rail Transit	Bus Rapid Transit
Maximum Passengers per Car	150	116	160
Maximum Cars per Driver	10	4	1
Practical Capacity (pass/hr/direction)	60,000+	10-12,000	10-20,000
Operating Speed (km/hr)	30-40	20	17-20

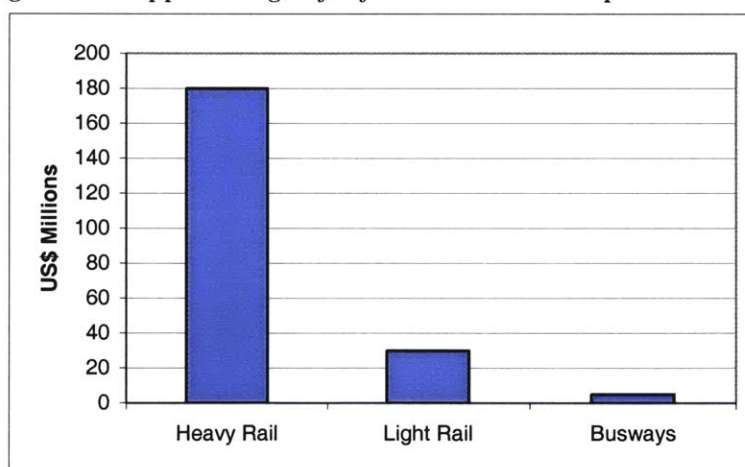
[Source: DFID]¹⁵¹

¹⁵¹ Department for International Development, (2002). *World Bank Urban Transport Strategy Review – Mass Rapid Transit in Developing Countries*.

5.4.2 Infrastructure and Operating Costs

When comparing the forms of MRT in terms of infrastructure costs, BRT comes out the clear winner. One of the main reasons BRT is so much cheaper, is that it usually is implemented on existing city streets. Depending on conditions, BRT infrastructure can cost between US\$1-5 million per kilometer, not including buses. LRT is also much cheaper than HRT because it is most commonly developed at grade. The average infrastructure cost of LRT is between US\$10-30 million per kilometer. HRT systems are the most expensive form of MRT. When built at grade they cost between US\$15-30 million per kilometer, elevated they cost between US\$30-75 million per kilometer, and underground they cost between US\$60-180 million per kilometer. While HRT is the most expensive, it also has the longest system lifetime. BRT vehicles often need to be replaced every 10-12 years; LRT vehicles need replacement on average every 50 years, and HRT vehicles can last from 50 to 100 years. When considering the lifecycle costs of the three MRT systems, HRT and LRT have greater value.

Figure 67: Upper Range of Infrastructure Costs per Kilometer



[Source: DFID]¹⁵²

¹⁵² Department for International Development, (2002). *World Bank Urban Transport Strategy Review – Mass Rapid Transit in Developing Countries*.

5.4.3 Environmental Costs

MRT has significant environmental benefits over the use private automobiles, in terms of energy efficiency and pollutants per passenger mile traveled. This efficiency comes from greatly increasing the density of passengers per vehicle. Within the three forms of MRT discussed, the environmental benefits vary based on capacity and power source. BRT vehicles are powered by combustion engines that run on a variety of energy sources including: diesel, compressed natural gas, gasoline, liquefied natural gas, and propane. LRT vehicles are powered by an overhead contact system that connects to the pantograph, and delivers DC power at 650-750 Volts. HRT vehicles are powered by a third rail traction power system that delivers AC or DC at 650-750 Volts. The least efficient form of transit is BRT, which consumes 4,415.2 Btu per passenger mile. LRT consumes 74 percent less energy per passenger mile than BRT. HRT is the most efficient form of MRT; it consumes only 911.3 Btu per passenger mile, which is 79 percent more efficient than BRT.

Figure 68: United States Energy Efficiency of Public Transportation, 1998

Transit Mode by Fuel	Btu/Vehicle Mile	Btu/Passenger Mile
Bus Total	41,338	4,415.20
Heavy Rail– Electric	19,789	911.3
Light Rail– Electric	29,688	1,152.80

[Source: APTA]¹⁵³

In terms of pollution emissions, BRT is the highest contributor to CO, NOx, and CO2 pollution of all three forms of MRT. HRT is the least polluting form of MRT.

¹⁵³ American Public Transportation Association, (2002). *Conserving Energy and Preserving the Environment: The Role of Public Transportation*. www.apta.com/info/online/shapiro.htm

*Figure 69: United States Pollution Emissions by Public Transportation, 1999
(Grams per 1000 passenger miles)*

	VOCs	CO	NOx	CO2
Buses	0.25	1.30	1.33	266.81
Heavy Rail	0.04	0.49	0.00	170.43
Light Rail	0.56	0.65	0.01	228.10

[Source: APTA]¹⁵⁴

5.4.4 Social Equity

All forms of MRT contribute to social equity through general improvement of mobility. Furthermore, the effects of poverty can be directly reduced when MRT is a major carrier of the poor, and indirectly through the benefit the poor receive from overall economic prosperity.¹⁵⁵ It is difficult to measure the contributions to social equity of the various forms of MRT against each other, yet BRT and HRT seem to have a greater impact than LRT. BRT is by far the cheapest form of MRT to build, and this translates directly to lower passenger fares. The fares for HRT are usually more expensive, but the capacity, and speed are greater, offering a more efficient mode of transportation. HRT also has a greater impact on the regional economy, urban development patterns and contributes significantly less pollution than BRT.

¹⁵⁴ American Public Transportation Association, (2002). *Conserving Energy and Preserving the Environment: The Role of Public Transportation*. www.apta.com/info/online/shapiro.htm

¹⁵⁵ Department for International Development, (2002). *World Bank Urban Transport Strategy Review – Mass Rapid Transit in Developing Countries*.

6 Recommendations and Closing Remarks

Due to the rapid development and urbanization of Guangzhou, the city is faced with one of the largest growing motor vehicle fleets in the world. This trend of motorization is causing major stress on the environment, economy, and society. The municipal government is aware of the problem, and recognizes the urgent need for a new and more sustainable transportation alternative.

6.1 Guangzhou Metro

The prominent method Guangzhou has chosen to combat the negative effects of the automobile is Heavy Rail Transit (HRT). The city has established both a near and long-term plan to implement an extensive HRT system. This long-term commitment is the first and most critical step towards improving the environment in the region. Yet just placing the rail network will not produce the desired benefits. If the rail network is not implemented under a larger strategic development program it may have negative economic impacts on the municipal government and the region. For the Guangzhou Metro system to have a significant impact on the energy efficiency, air pollution, and economic development of the region it must be implemented in coordination with supportive planning and policies at both the regional and local level.

Yet, designing and implementing such a suite of policies may be the most difficult objective. Guangzhou lacks the institutional structure to provide policies that inclusively cover the areas of urban planning, transportation, the environment, and economic development. For comprehensive planning and policies on both the regional and local scale to come to reality there is a need for greater institutional capacity and interconnectivity. The institutional arrangement needs to promote cross-boundary, multi-disciplinary governance that will produce comprehensive systems solutions to the problem of urban transportation. The Guangzhou municipal government has the knowledge capital necessary to implement such an institution, yet this has yet to be achieved.

The Guangzhou Metro is in its infant stages and has a great opportunity to initiate comprehensive policies and plans from the start of operations on lines 2 and 3. Combining the lessons from the cases presented in this thesis and utilizing the TOD strategies in Chapter 2, will give Guangzhou a good starting point for creating their own suite of policies and planning guidelines.

6.2 Lessons Learned

While there are many examples of successful Transit Oriented Developments, there is no perfect case or example that can be used universally as a template. Each of the cases presented in this thesis offer insights into what has worked in specific cities, yet the cities presented were vastly different in terms of population, GDP, geography and so forth. The purpose of these cases was to compile the lessons from several cities, spanning both the developed and developing world, and present a simple set of guidelines for future TODs.

Each of the cities studied have been successful in implementing certain aspects of the “model” TOD. By utilizing the positive lessons and combining them into an inclusive suite of planning, and policies we can take bold steps to improving the energy efficiency and sustainability of our cities. There are three themes that emerge from this analysis that represent the basis for a successful TOD: there is a clear need to link land-use planning and transit development; to implement reinforcing and comprehensive policies; and to gain public/private support for TOD.

6.2.1 Linking Land-Use and Transit Development

Without long-term strategic planning urban areas will take shape in a different pattern and form than urban transit. This divergence will cause a disconnect between housing and transportation and will lead to increasingly inefficient modes of transportation. The key to overcome this trend is to create a long-term plan that both limits the growth of the

urban area and provides strategically located transit corridors. These corridors must have the scope, scale, and interconnectivity to effectively provide transportation throughout the entire city, and create the necessary linkage of land-use and transit. This not only limits the size of the city, but also shapes where new growth will occur. Portland, Oregon, achieved this long-term planning successfully with an Urban Growth Boundary, and their investment in the MAX light rail system.

6.2.2 Reinforcing Policies

In order for the TOD to be successful there must be a significant shift from the private automobile to transit. For this to occur, there must be a suite of policies in place that support the goals of the TOD. These policies must work to reshape the urban form, reduce the vehicle miles traveled, and improve transit ridership. These policies must be reinforcing and comprehensive in nature. A sample of policies that achieves this are as follows: Vehicle pricing and restriction; bicycle and transit promotion; streamlined permitting for transit oriented and supportive developments; rezoning for higher densities in a half mile proximity to transit stops. These are just a few policies work together to encourage alternate modes of transportation, and increase the density urban nodes. Bogotá is transforming the face of their city through the implementation of Bus Rapid Transit and supporting vehicle restrictive, and transit promoting policies.

6.2.3 Public/Private support

For government's policies and planning to be successful they must have the support of both the private sector and the general public. The support of the private sector is gained by making TODs economically profitable. This is achieved through establishing transparent joint development programs, and streamlining the permitting process. The support of the general public will be achieved by developing public transportation that is attractive and efficient. Successful transit networks must not only be integrated into the fabric of the communities, but they must serve to revitalize and integrate the entire. The support of the private sector and the general public are critical to the success of the

TODs, and must be incorporated into the decision making process. Washington DC was very successful at elevating the status of public transportation by building beautiful transit stations. They were also successful at revitalizing many communities through joint developments.

6.3 Comprehensive Approach

The main purpose of TOD is to fight the negative impacts of urban sprawl, and reshape travel patterns and land-use into a more sustainable form. To achieve the full potential of a TOD it is critical to have long-term strategic planning, and cross-jurisdictional, complementary, and comprehensive policies and institutions. As was demonstrated in the introduction, single policies aimed at one facet of the problem will not provide the desired solution. Policies must be made in suites that cover a broad area both geographically, and sectorily. To effectively reduce energy consumption through TOD the policies must span multiple jurisdictions and cover the areas of transportation, urban planning, and land-use. These policies must be aimed at reducing vehicle miles traveled while bolstering transit ridership.

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